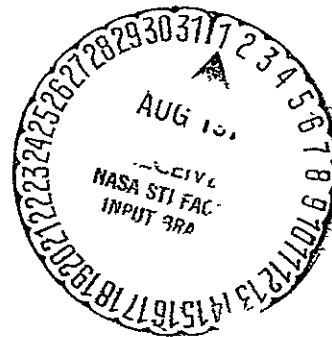# FEASIBILITY STUDY OF AN INTEGRATED PROGRAM FOR AEROSPACE-VEHICLE DESIGN (IPAD) SYSTEM

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VOLUME I

SUMMARY

30 August 1973

FEASIBILITY STUDY OF AN
INTEGRATED PROGRAM FOR AEROSPACE-VEHICLE
DESIGN (IPAD) SYSTEM

VOLUME I	- SUMMARY

VOLUME II   - CHARACTERIZATION OF THE IPAD SYSTEM
                            (PHASE I, TASK 1)

VOLUME III   - ENGINEERING CREATIVE/EVALUATION PROCESSES
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FOREWORD

This investigation was conducted for the NASA Langley Research Center by the Convair Aerospace Division of General Dynamics Corporation under Contract NAS 1-11431.

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1 INTRODUCTION

The design of a new aerospace vehicle is presently a complex, long-term process. At the onset, a set of objectives is identified in the areas of mission, weight, performance, payload, range, etc., which are specified with a fairly good knowledge of the available design technology and constraints. The designer's goal is to minimize cost, while meeting basic project objectives. The designer possesses a fund of accumulated experience and knowledge which he applies, with intuition, to the requirements and constraints he has been given. The knowledge and experience of the designer are more and more frequently being delegated to the computer; the intuition and imagination can never be. Some of the purposes of the IPAD feasibility study were to determine what sections of the design process are amenable to automation; how much monitoring must the automation have; how can the design process be effectively organized; and, most important, how can the management/designer/engineer team members retain the visibility and control necessary to exercise their intuition and imagination in the design process.

The introduction of automation is a significant change in the design process; however, the important management aspects of this change are not only related to the technical details of engineering disciplines, programming, data bases, etc., but the key to success also depends upon managing the adaptation required of the people involved in the use of the automated process.

Automation of any process requires not only a thorough knowledge of the process, but of the pivotal factors that drive and control it. When the process involves the myriad details of project team data flow and communications, many programs and subroutines, thousands of variables, and the ramifications of computer operating system characteristics, it is easy to lose sight of the fact that it is still the designer — the engineer — who is the key driver and decision-maker in the process.

Although the various volumes of this report describe some of the considerations necessary for the technical basis needed to successfully automate the design process, the underlying, guiding philosophy has been that of providing a tool adapted to the needs of the members of a management/designer/engineer team--the ultimate users--and that is a truly useful tool. The acknowledged principle has been that the engineer and his management are generally more interested in solving the design problem than in becoming a better communicator with the computer.

The scope of the total IPAD feasibility study is illustrated in Figure 1-1. The study was divided into the following eight tasks within two study phases:

1

2

DETERMINE EXTENT OF PRESENT COMPUTERIZED DESIGN PROCESSES

EXAMINE PRESENT METHODS OF DESIGN

DETERMINE INFORMATION NEEDED TO DESIGN VEHICLE

WEIGHT SIZE
PERFORMANCE

METHODS TO MONITOR PROCESS INTERACTIVELY

GENERALIZED OPTIMIZATION TECHNIQUES

DIFFERENT FORMS OF INTERFACES

DESIGN IPAD SYSTEM

METHODS TO INCLUDE EMPIRICAL & EXPERIMENTAL TECHNIQUES

STRUCT

WHICH DISCIPLINES SHOULD BE INCLUDED IN AUTOMATED DESIGN

STRESS

AERO

WEIGHT

PROPULSION OM

IPAD

SYSTEM CONSTRAINTS

STRUCTURES OM

INTERACTIVE

WEIGHT OM

DATA BASE

DATA REQUIREMENTS TO INTERFACE DISCIPLINES

METHODS TO INCLUDE GENERAL FORMS OF DESIGN PROGRAMS

DISCIPLINES NOT COMPUTERIZED THAT SHOULD BE

IPAD SYSTEM FLOW CHARTS & DETAILED SUBROUTINE DESCRIPTIONS

IMPACT UPON TRADITIONAL ORGANIZATION

BETTER DESIGN

FASTER

BETTER WAY TO DO IT

BENEFITS FOR USING IPAD

NON-AEROSPACE BENEFITS

COSTS + DEVELOPMENT & OPERATION

IMPLEMENTATION SCHEDULE

Figure 1-1. Flow Chart of IPAD Study

PHASE I

STUDY PLAN COORDINATION

TASK 1 - CHARACTERIZATION OF IPAD SYSTEM
Define an IPAD Engineering Usage Philosophy
Identify Feasible Automated Design Procedures
Evaluate Adequacy of Existing Computer Programs
Recommend Areas for Further Development
Determine IPAD Feasibility and Applicability
Recommend IPAD's First Release Engineering Capability

TASK 2 - DESIGN OF IPAD SYSTEM
Define a Systems Operating Philosophy
Evaluate System Design Options
Identify Elements of IPAD's Utility Library
Investigate Organization and Management of Data Bank
Determine Number and Type of Input/Output Terminals
Determine Host Computer Complex Configurations Adequate
for IPAD
Recommend IPAD's First Release Computer System Capability

PHASE II

TASK 3 - IPAD IMPLEMENTATION SCHEDULE
TASK 4 - IPAD SYSTEM DEVELOPMENT COST
TASK 5 - IPAD SYSTEM OPERATIONAL COST
TASK 6 - IPAD SYSTEM BENEFIT ASSESSMENT
TASK 7 - IPAD IMPACT ON COMPANY ORGANIZATION
TASK 8 - IPAD SPIN-OFF ASSESSMENT

Figure 1-2 summarizes the main features of an IPAD system as
presently conceived and described elsewhere in this report.

3

IPAD IS:

- AN INTEGRATED SYSTEM OF AUTOMATED MODULES.
  EACH DISCIPLINE IS RESPONSIBLE FOR ITS OWN CAPABILITY DEVELOPMENT, UPDATE & GROWTH

- A USER-ORIENTED & DIRECTED MODULAR SYSTEM WITH FLEXIBILITY FOR CHANGE, ADAPTATION & EXPANSION

- A HARDWARE/SOFTWARE COMPUTER SYSTEM DESIGN APPROACH
  TO PERFORM ENGINEERING DESIGN PROCESSES MORE EFFECTIVELY, ECONOMICALLY & SWIFTLY

- A COMPUTER SYSTEM STRUCTURE
  USABLE IN MANY ENGINEERING & SCIENTIFIC FIELDS

- ITS DATA BANK IS THE REPOSITORY FOR ALL DESCRIPTIVE & INFORMATIVE DATA GENERATED BY THE ENGINEERING/SCIENTIFIC TEAM FOR A SPECIFIC PROJECT

- A MANAGEMENT TOOL
  TO PROVIDE IMMEDIATE VISIBILITY INTO PRODUCT STATUS & PROGRESS

- INITIALLY, A REASONABLE ENGINEERING CAPABILITY (SET OF AUTOMATED MODULES) MOUNTED ON A STATE OF THE ART HARDWARE/SOFTWARE STRUCTURE THAT CAN BE READILY IMPLEMENTED

- ULTIMATELY, A COMPREHENSIVE, DYNAMIC ENGINEERING TOOL SUPPORTED BY EFFICIENT, COST-EFFECTIVE HARDWARE/SOFTWARE CAPABILITY

- AN EDUCATIONAL AID FOR TRAINING NEW ENGINEERS IN THE USE OF VARIOUS DESIGN PROCESSES

IPAD IS NOT:

- A SINGLE, HARDWIRED COMPUTER PROGRAM

- AN AUTOMATED, SINGLE-PURPOSE PROCEDURE

- A DISLOCATED ARRAY OF RANDOMLY COLLECTED COMPUTER PROGRAMS

- A SYSTEM OF PROGRAMS TO BE RUN BY A SINGLE DISCIPLINE

- A SYSTEM OF PROGRAMS IMPOSED BY AN AGENCY (OR COMPANY) ON THE AEROSPACE INDUSTRY COMMUNITY

Figure 1-2. Major IPAD Features

2 IPAD OVERVIEW

IPAD was conceived and organized to make possible the automated implementation of a design. As such, it is not bound by any paricular level of sophistication in design, in analytical·techniques, in estimating procedures, or in level of detail in input; instead, it is amenable to the level of need of its users for any particular job. The principal characteristic of the design philosophy for IPAD has been its consistency in treating the various aspects of the design with a uniform depth of attention so that the end product can have a balanced consideration of all factors involved. IPAD will be flexible and it will be open-ended since it must be able to absorb new developments in design, analytical techniques, and computer.system technology as they occur. Rather than a computer program, IPAD is a system of automated procedures providing a framework within which aerospace vehicle design can be accomplished.with speed, efficiency, and confidence.

2.1 Goals and Objectives

The overall goal of IPAD is the automation of appropriate sections of the design process to shorten design time, reduce cost, and improve the ultimate product.

The objectives of the present study were to:

Develop IPAD's Operational Philosophy
Establish Extent of IPAD Support of the Design Process
Investigate System Organizational Options
Determine the Feasibility of an IPAD System
Generate an IPAD System Design
Recommend IPAD's First Release Capability
Establish IPAD Implementation Schedule and Cost
Estimate IPAD System Operational Cost
Assess·IPAD Benefits
Determine Potential Impact on Company Organization
Assess IPAD Spin-off.

A series of studies were performed in pursuit of these objectives including the following:

1. Design Process

    a. Characterize the design process dividing it in various design phases, and segregate the basic functions performed by several representative design/engineering disciplines in each phase.

b. Identify the interdisciplinary data flow for manual/automated procedures and man-machine interfaces occurring in the design process.

c. Evaluate the adequacy of existing computer programs and operating modules for use in IPAD.

d. Define an IPAD usage philosophy from the engineering user point of view.

e. Identify optimization techniques to be included within an IPAD system.

f. Recommend IPAD's first release engineering capability.

2. Computer System.

a. Define the system operating philosophy and evaluate system design options.

b. Investigate the organization and management of the Data Bank.

c. Identify and describe the software elements of a Utility Library for IPAD.

d. Determine the number and type of Input/Output Terminals.

e. Determine host Computer Hardware/Software Complex configurations adequate for IPAD.

f. Evaluate language and size limitations of existing operational modules.

g. Recommend IPAD's first release computer system capability.

3. Implementation Schedule and Cost.

a. Basic implementation plan.

b. Alternate implementation plans.

4. Operational Cost.

a. Identifiable cost increases.

b. Identifiable cost decreases.

5. Benefit Assessment.

a. Performance of aerospace vehicles.

b. Engineering work.

c. Disciplinary interfaces.

6. Impact on Company Organization.

a. Management implications.

b. Near-term organizational impact.

c. Future organizational impact.

7. IPAD Spin-off

    a. Non-aerospace technical fields.

    b. Non-aerospace business fields.

2.2 IPAD Organization

An IPAD system is defined herein as consisting of four major components, as shown in Figure 2-1: (1) A Management Engineering Capability represented by a battery of automated Operational Modules for various management/design/engineering disciplines, (2) an IPAD Framework Software which supports and augments the Engineering Capability, (3) an Operating System Software, which features a comprehensive Data Base Management System, and (4) a Computer Complex Hardware, on which all the Engineering, IPAD, and System software will be mounted and exercised. From this statement, it can be inferred that the Management/Engineering Capability can and should be tailored to the specific needs of the management/design/engineering team (i.e., the battery of Operational Modules for aircraft design would be different than that for missiles, or navy vessels, or terrestrial vehicles, or civil engineering projects, although many common elements could be identified). On the other hand, the IPAD Framework Software, the Operating System Software, and the Computer Complex Hardware could have essentially the same basic capabilities for all users, with freedom of choice in specific software, and type and quality of equipment desired within each computer complex.
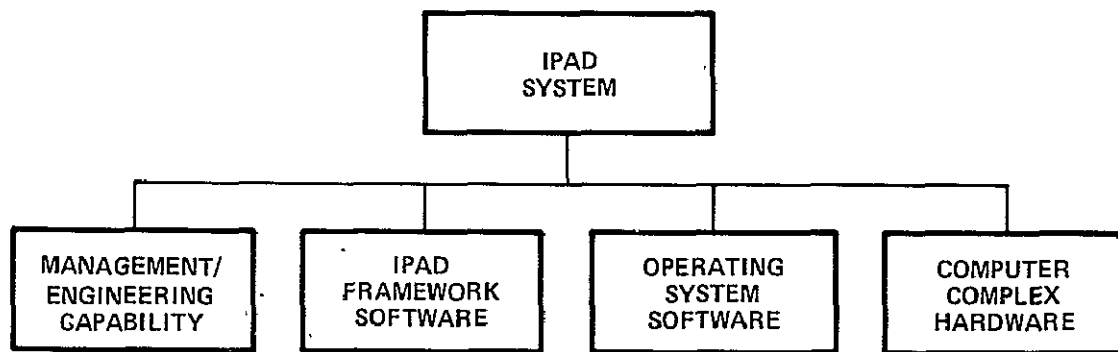
Figure 2-1. Major IPAD System Components

    The organization, engineering usage philosophy, and the accompanying IPAD design concept developed in this study provide the flexibility required to satisfy the project needs of any management/design/engineering team which will use and exploit the IPAD system's capability in any way it sees fit.

2.3 Engineering Usage Philosophy

Figure 2-2 gives an overview of the interrelationships among the four major components of IPAD and illustrates the engineering usage philosophy. The more important elements of those components and the usage philosophy itself are discussed in the following paragraphs:

2.3.1 <u>Management/Engineering capability</u>. - The elements in this area are:

1. The User. IPAD has been conceived and designed around a Project Team as its main user, to enhance team creativity through effective communications and interaction among its members. An individual user will participate in the design process using the IPAD System in either of four different modes:

    a. Interactive monitoring, which puts at his disposition the most capable interactive devices, mini-computers, host computer, and all features of the IPAD System. This mode will be used mostly with interactive Operational Modules to monitor input/output (alpha-numeric, graphical, or both) by either: (1) single project team members in performance of their individual tasks, or (2) several members interacting with each other in sequential or iterative activities involving one or more design/engineering disciplines.

    b. Batch spin-off, whereby the user starts a task in the interactive mode and ends it by requesting an immediate batch processing (perhaps requiring long execution time) while he performs other tasks.

    c. Interactive typewriter, which enables him to access a reduced set of the IPAD System capability. This mode will be mainly used with interactive Operational Modules requiring small amounts of input/output data transmission.

    d. Batch, which from the operations point of view provides a capability similar to present usage of computers, although with the benefits of data base management and other features of the IPAD System. This mode will be principally used with non-interactive Operational Modules or production jobs that do not require a man in the loop. The batch processing can be requested either from an interactive device, a remote terminal, or by direct submittal to the computer operations desk.

2. Automated Operational Modules. The total automated capability of the engineering/science community is resident in a library of automated operational modules consisting of both a public domain library, accessible to all parties, and private libraries containing modules with limited or restricted availability
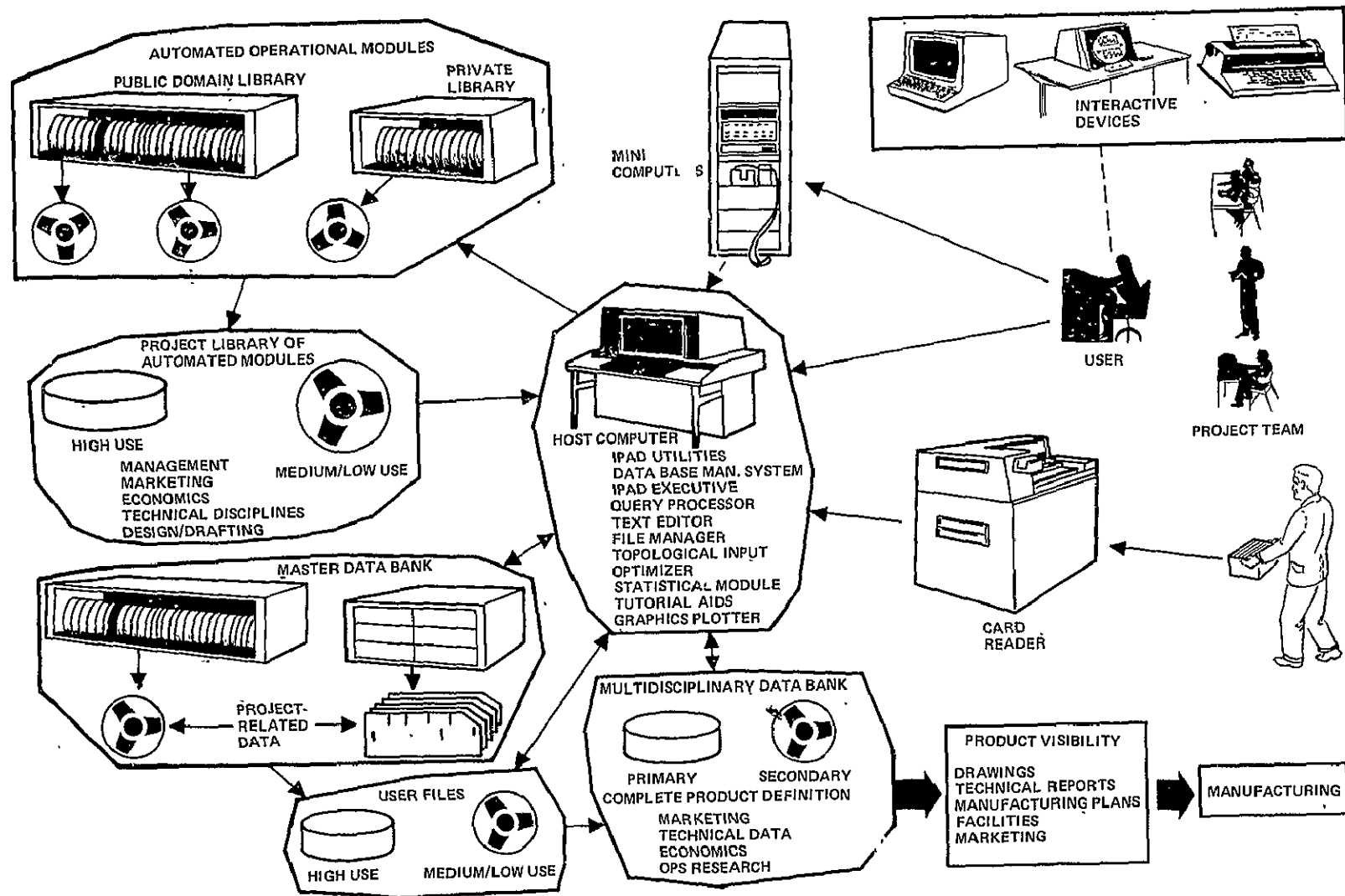
Figure 2-2. IPAD Overview

due to the nature of its contents being private data, classified information, or the like. From the total gamut of available modules a project team will select those which are applicable to their specific project to assemble a project library of automated operational modules that will be installed on the IPAD Computer Complex. The contents of this library are dynamic in the sense that programs are added or removed from it as the need arises, and are resident on disk or tape depending on their usage rate. All project related activities such as management, marketing, economics, technical disciplines, and design/drafting will have their respective automated capabilities installed in the system. The position of this software in relation to other computer software required for IPAD is shown in the first two columns of Figure 2-3.

3. Master Data Bank. This bank is the repository of all historical, statistical, and other data that has been accumulated from previous studies and which are a vital part of the experience of a design team. The contents of this bank are both of the public-domain and the private-data type but most predominantly of the latter one. Typical contents of this bank would be weight statistical data, raw or curve fitted test data for aerodynamics, propulsion, structures, etc; engine data; design criteria and specifications; standard parts; subsystems data; and many others. The project team members will select from this bank that data which is pertinent to their project and place it in residency on disk or tape, depending on the extent of the data and its usage rate.

4. The Multidisciplinary Data Bank. Now the user — with the engineering know-how described in 2. and 3. above and the rest of the IPAD System components described in paragraphs 2.3.2 to 2.3.4 — is ready to devote his attention to generating the data that will completely define the product, including all technical groups, marketing, economics, operations research, etc. Most of this data will be contained in the Multidisciplinary Data Bank for proper access by all parties concerned. The inflow of data into this bank is supervised by the project Data Bank Administrator, who ensures that the data is reviewed and approved before it is inserted in the bank.

5. Product Visibility. Data contained in the Multidisciplinary Data Bank at any stage of the design can be used to provide product-related visibility in terms of drawings, technical reports, manufacturing plans, facilities, marketing, etc. The final set of data defines the product that goes to manufacturing.

2.3.2 The IPAD framework software. - From the user's point of view, IPAD is a framework which supports and augments the capabilities of his computerized management, design/drafting, and analytical tools. From this viewpoint, the framework is composed of a number of utilities and interfacing capabilities, as shown in Figure 2-3. The elements of this software are:

Figure tree — Computer Software for IPAD

COMPUTER SOFTWARE FOR IPAD

- MANAGEMENT/ENGINEERING CAPABILITY SOFTWARE
  - EXECUTABLE CODE
    - OM SOURCE
    - OM OBJECT
    - DBMS CODE
    - SPECIAL CODE
  - NON-EXECUTABLE CODE
    - SUBSCHEMA
    - INPUT/OUTPUT DEFINITION
    - TUTORIAL AIDS SUPPORT
    - TASK CONTROL SEQUENCES
- IPAD FRAMEWORK SOFTWARE
  - IPAD EXECUTIVE
    - IPAD CONTROL LANGUAGE
    - INTERCEPTOR
    - EXPANDER
    - WRITER
    - RECORDER
  - GENERAL PURPOSE UTILITIES
    - STATUM
    - OPTUM
    - GGP
    - GDM
    - QUERY PROCESSOR
  - SPECIAL-PURPOSE UTILITIES
    - DML INSERTION PREPROCESSOR *
    - SUBSCHEMA ASSEMBLER
    - SCHEMA ASSEMBLER
  - NON EXECUTABLE CODE
    - TASK CONTROL SEQUENCES
    - PROJECT SCHEMA
- OPERATING SYSTEM SOFTWARE
  - DATA BASE MANAGEMENT SYSTEMS (DBMS)
    - SET PROCESSOR
    - PRIVACY
    - DMCL
  - COMPILERS
    - FORTRAN *
    - COBOL *
    - BASIC *
    - ALGOL *
    - JOVIAL *
    - DDL * *
  - SUBSYSTEMS
    - BATCH
    - TIMESHARING
    - TEXT EDITOR
    - GGL
    - REAL TIME

*Enhanced for Data Manipulation Language (DML)
** Supporting DML enhanced compilers

Figure 2-3.   Computer Software Associated with IPAD

1.   The IPAD EXECutive function, which provides control of the full capability of the host operating system/timesharing subsystem and is interfaced by: tutorial aids and the ability to code, save, and execute pre-established task sequences.

2.   The General Purpose Utilities, which include:

a.   The Query Processor, which provides interface with a project-oriented Multidisplinary Data Bank and the Data Base Management System.   To the user, the Data Base and Query Processor provide for accurate and efficient communication with respect to task assignments and task status, and efficient access to pertinent design data, design tools, and operating modules.

b.   A statistical utility (STATUM) and a general-purpose optimization utility (OPTUM), which provide general engineering capability in these areas.

c.   A General Graphics Plotter (GGP), and a General Drafting Module (GDM), which provide multipurpose plotting and design/drafting capabilities, with access to hardcopying equipment.

   The foregoing three major groups of general purpose utilities make up the basic capability.   Additional utilities could be added in the future, or, conversely, some elements of this capability could be absorbed by the operating system.

3.   The Special Purpose Utilities, which provide a capability to incorporate Operational Modules and to assist the user in preparing existing modules for operation within the IPAD Framework.

4. Non-excutable Code,which provides a task integration capability and permits the construction of a task oriented user file appendage to the data base, and the construction of a Data Base Management System interface to share data among the Operational Modules.

2.3.3 The operating system software. - This software usually resides in disk and consists of : system utilities to support the user, such as compilers, assemblers, translators, file managers, etc; the operating system library, containing system-support entities such as the resource allocator, the job scheduler, the record manager, the loader, etc.

Features of the operating system software which are considered important to IPAD include: random access files, which are deemed to be required by current and projected mass storage hardware for fast access/retrieval times; index sequential files, which combine both random and sequential features; permanent files, required for continuous availability of information contained in IPAD's data banks; an UPDATE utility, to selectively update while retaining prior data; an interactive communication subsystem, including time and memory sharing features to provide fast response times; and an interactive graphics subsystem, to provide capability for making graphs, drawings, pictures, etc. In relation to the latter feature, it is important to point out a pressing need within IPAD for a standard graphics language.

2.3.4 The computer complex hardware. - A particular host computer (i.e., a CDC CYBER 70 series) is used herein to illustrate a typical installation and its major components, as shown in Figure 2-4. The host computer is shown schematically in the center surrounded by the peripheral equipment. The illustrated host computer consists of the Central Processor Unit (CPU) and the Central Memory (CM),which form the high speed computing core of the unit; Peripheral Processors, which are small self-contained computers to handle peripheral tasks; optional Extended Core storage, which can be used to expand storage up to several million locations; Input/Output channels to communicate with the peripheral equipment; and the Operators Console, which provides the interactive interface with the host computer operating system software.

Disk storage holds the operating system, support utilities; and provides job residency, user residency (in the form of permanent files, accounting and system files), and disk packs for private user data, results from previous studies, etc.

The peripheral equipment includes: input/output handling equipment such as card readers/punches, magnetic tapes, paper tapes, and microfilm recorders; removable disk packs; interactive remote terminals, with hardcopying capability such
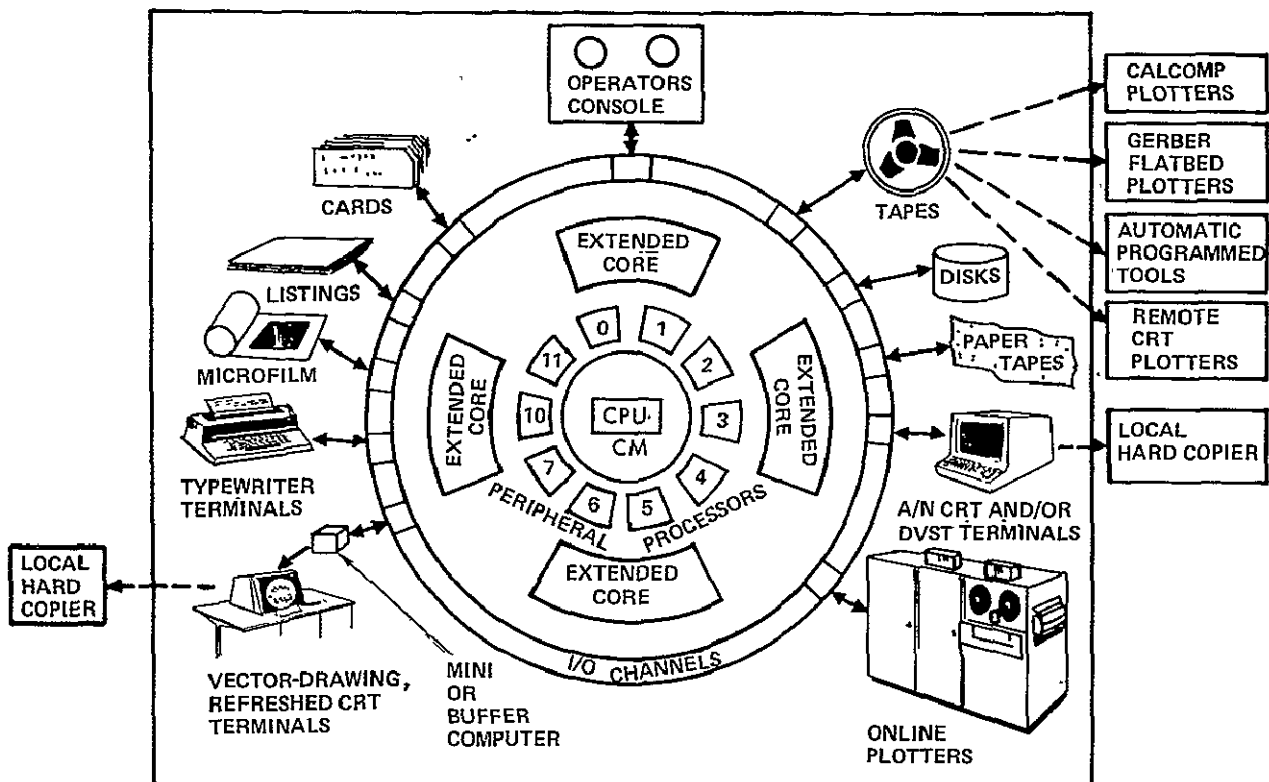
Figure 2-4. Typical Host Computer Complex Hardware

as typewriters, alpha-numeric graphics consoles, direct view storage tubes, and the more sophisticated large-screen, vector-drawing, refreshed terminals, usually serviced by a mini-computer; and remote units, typically fed from magnetic tapes, such as remote plotters, paper-ink plotters, drafting machines, and numerically controlled machines.

2.4 IPAD's First Release Capability

It is apparent that IPAD's capability for the NASA and the aerospace industry should be tailored to the needs of aerospace-vehicle projects. It is also clear that IPAD's goals ultimately call for all aspects of management and engineering to be represented with comparable capability within it. A logical approach to such an ambitious undertaking would be a phased program whereby an initial capability is first defined and assembled, subsequently exercised in real application cases to improve on the initial concept and design, and finally used to expand the implementation to all areas of interest. The objective of this section is to identify that initial capability.

The First Release Capability is defined herein as the nucleus of an IPAD System which incorporates all the major features identified in this study and that can be used both as a pilot working tool and to define IPAD's further development and implementation phases. The results of the evaluation studies performed during Task 1 "Characterization of the IPAD System", (Volumes II, III), and Task 2, "Design of IPAD System", (Volumes IV, V), were used to identify the main elements that should be contained in IPAD's First Release Capability. These elements were grouped into four major categories:

1. Management/Engineering Capability Software
2. IPAD Framework Software.
3. Operating System Software.
4. Computer Complex Hardware.

2.4.1 Management/engineering capability software. - It was concluded that all basic aspects of the design process must be included to provide an "integrated system" and that they must have the degree of representation required to make IPAD's First Release Capability a working tool. The three basic questions that must be answered are:

1. What disciplines should be initially included?
2. What Operational Modules are needed for each discipline?, and
3. What priority should be assigned for concurrent and/or sequential implementation of these Operational Modules in relation to other needed IPAD software?

In answer to the first question it is recommended herein that the following Operational Modules be included mainly by refurbishing existing software, and to a lesser extent by developing new programs where absolutely necessary

1. Management.
2. Vehicle Synthesis.
3. Configuration Design.
4. Aerodynamics.
5. Performance.
6. Propulsion.
7. Mass Properties.
8. Flight Control and Stability.

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9. Design Specifications/Criteria.

10. Subsystems Design (various).

11. Loads

12. Structural Analysis/Synthesis.

13. Structural Dynamics.

14. Materials.

15. Thermodynamics.

16. Operations Research/Reliability.

17. Economic Analysis.

18. IPAD Specifications/Tutorials for new Operational Modules.

The answer to the second question is that the engineering capability within the First Release Capability shall include automated procedures to perform all the disciplinary functions identified in Section 3 of Volume II, and comparable capabilities for Management, Design Specifications/Criteria, Materials, and IPAD Specifications/Tutorials that are not treated in detail therein. The core of each disciplinary Operational Module shall contain the computer programs identified in this study or equivalent programs from other agencies and aerospace companies provided they perform the same individual functions or an aggregate of them. The philosophy behind the assembling of each disciplinary Operational Module for the First Release Capability is to start by adapting existing automated procedures, making them interactive as required, and interfacing them with the system by means of the Special Purpose Utilities. Where automated capability is lacking, the thrust should be in developing the Operational Modules themselves but now they can be planned with all IPAD features in mind for maximum efficiency and responsiveness to user needs. By these means a disciplinary Operational Module will become an aggregate of automated procedures supported by a series of general purpose and special utilities which will be adequate for IPAD's First Release Capability. Any further improvements on Operational Modules should fall under the category of general technology development with the only provision, perhaps, of meeting specific requirements for ease of insertion in IPAD. A set of tutorial aids could be easily assembled for this purpose.

The answer to the third question is that a compromise solution must be worked out to harmonize the development of the new IPAD framework software with the upgrading of the engineering user tools so he can fully exploit the IPAD System. This is so since both capabilities complement each other; that is, the new system software must exist to make it possible for an engineering team to work in the new

design environment it creates, and on the other hand the tools that the team uses must be upgraded to exploit the new software system. Since a wealth of engineering capability exists, and provisions to accept existing Operational Modules have been included in the design of IPAD (i.e., the Special Purpose Utilities), it is apparent that the new IPAD framework and operating system software should be given developmental priorities. Furthermore, the implementation plan summarized in Section 5.3 of this volume clearly indicates that several elements of the new IPAD software are on the critical path of the implementation schedule.

2.4.2 IPAD framework software. - The First Release Capability of IPAD must include the following elements:

1. The IPAD EXECutive, which is the principal contact that the IPAD user has with the system. The EXEC is additionally supported by four utilities:

   a. The Task Control Sequence Skeleton Writer, which is an interactive program to assist the user in writing a sequence of automated tasks.

   b. The Task Control Sequence Skeleton Expander, which is an interactive (or batch) program to assist the user in tailoring a task sequence to his specific application.

   c. The Interceptor, which enables the user to maintain a record of his transactions.

   d. The User's Task Trajectory Recorder, which performs automatic recording of the sequence of transactions in which the user was actually engaged.

2. General Purpose Utilities, to provide an augmentation of the user's Operational Modules. There are five general purpose utilities in the present design of IPAD, some of which are highly modular and can be developed in various release levels as discussed below.

   a. The statistical utility module (STATUM), which provides the user with a statistical package that can be used at an interactive terminal is not an indispensable element for a First Release Capability, but on the other hand its development cost is small (15 man-months and 10 computer hours, reference Volume VI, subsection 2.5.6) and would deprive the user of a convenient interactive tool if not developed. A progressive release will not provide worthwhile relief in costs or schedule and therefore it is recommended that the STATUM be implemented for the First Release Capability.

   b. The general purpose optimizer (OPTUM), which provides the user with an interactive collection of multivariable search techniques and tutorial aids for optimization and parametric studies, fulfills one of the basic

needs of a project engineering team. Its modularity permits releases at various levels of capability, but here again its total developmental costs are relatively small (21 man-months and 15 computer hours, reference Volume VI, Section 2.5.6). It is recommended that the total capability defined elsewhere in this report be implemented for the First Release Capability.

c   The Query Processor, which is an interactive COBOL program that enables the user to control and manipulate the contents and structure of his data sub-bases, is considered to be an indispensable element of the First Release Capability. It represents perhaps the most widely (to be) used IPAD general purpose utility, and it is the third least expensive one (i.e., 25 man-months and 20 computer hours, reference Volume VI, Section 2.5.6).

d.   The General Graphics Plotter, which addresses the need of producing the geometrical, graphical and pictorial displays required by interactive users in any design process, is a basic element of the new IPAD design environment and must be implemented for the First Release Capability. It is highly modular and considerable design and implementation is presently underway in industry at large. The impact of this current development activity could substantially reduce the costs estimated for this task in Volume VI, subsections 2.5.6.8 and 2.5.6.9 (i.e., 96 man-months and 46 computer hours).

e.   The General Design Module, which augments the design function through interactive-design/automated-drafting software and equipment, is the cornerstone of board design activities in the new IPAD environment. It is destined to be the largest, most system-demanding, and second most frequently used IPAD utility (after the Query Processor). It is perhaps the most modular utility and involves the development of large amounts of new code. Due to the criticality of response time for the design function, this module is to be supported mainly by a minicomputer with proper interfaces to the host operating system. The basic elements of this module are a comprehensive information storage and retrieval system, 3-D geometrical building blocks, and design and analysis program libraries. The approach recommended is to implement progressive levels of release to provide an initial capability for IPAD subsystems checkout, and then culminate with an adequate number of modules and library contents to permit a project-oriented demonstration of IPAD at First Release Capability.

3.   The Special Purpose Utilities, to assist IPAD users in interfacing their computer programs with the Data Base Management System for which a great

deal of information is required. Without the support of the utilities this interfacing would entail a prohibitive amount of time and labor. These utilities are considered indispensable for all release capabilities of IPAD. They are:

a. The Data Manipulation Language Insertion Preprocessor, which is a batch utility to replace conventional FORTRAN input/output coding with logically equivalent Data Manipulation Language statements.

b. The SUBSCHEMA Assembler, which is an interactive utility to extract data descriptors from the conventional input/output of a program and generate Data Description Language statements to interface with the data base.

c. The SCHEMA Assembler, which is an interactive utility to integrate several computer programs into one execution sequence and resolve conflicts with common and duplicated data items, data base structure, and required transformations.

4. Non-executable Code, to define the extensive data base organization related to the selected aerospace-vehicle project activity, and to specify project-oriented task control sequences to be used during the demonstration of the First Release Capability.

2.4.3. Operating system software. – The First Release Capability of IPAD is designed to fully exploit the host computer's operating system software. In particular, the operating system must be upgraded to contain a capable timesharing (also called conversational) subsystem and a comprehensive Data Base Management System patterned after the language specifications of CODASYL's Data Base Task Group's recommendations. Two new languages must be developed: (1) a Data Description Language, to describe the data in the data base; and (2) a Data Manipulation Language, to cause the transfer of data between programs and the data base. The functions of the Data Base Management System are: (1) to control the input/output functions of the operating system to satisfy Data-Manipulation-Language requests issued by programs in execution; (2) to perform transformations to correlate SCHEMA and SUBSCHEMA data descriptions; and (3) to provide means of enforcing and maintaining the data integrity and logical structure detailed by the Data Base Administrator. The proposed implementation plan provides support to a FORTRAN Data Base Management System via COBOL and subroutine CALLs.

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2.4.4   Computer complex hardware.—The First Release Capability of IPAD will run on any of the large-scale, scientific computers available today providing they meet stringent hardware requirements.   Typically, all of the major, domestic large-scale scientific computer manufacturers have models which meet or exceed these requirements.   There is additionally a requirement to configure large disk-storage for IPAD's data bases.   A phased release to three major computing systems is included in the implementation plan.

Since IPAD is principally an interactive system, there is a requirement to provide interactive terminals for the users.   The terminal types selected for an IPAD environment are medium and large cathode ray tube graphics terminals.   A typical project is envisioned to require 26 medium capability and 10 large capability graphics terminals.   For additional details refer to Volume IV, Section 5.

Other equipment typically available in computer installations includes tele-typewriters, hardcopiers, drum and flat-bed plotters and drafting machines, etc.

In addition, an interactive large screen display system as illustrated in Section 3 of this volume should be included for presentation and review of project data during demonstration of the First Release Capability.

2.4.5   First release capability implementation.. Schedule and costs: Refer to section 5.3 of this volume for a summary of schedule and costs of the proposed implementation plan.

3 IPAD FUTURE DESIGN ENVIRONMENT

The basic underlying factor behind the implementation of an IPAD system is how to exploit the capabilities of a subordinate computing system to enhance the design activities of a project engineering team. Many and varied are the functions and tasks of members of this team. The new IPAD design environment must facilitate the tasks for all, and it can be justified only on a cost-savings/better-product basis. The potential cost savings are not the same for all the management/engineering functions within the design process. The potentials are greater for those functions which are involved with noncreative, repetitive tasks. As Figure 3-1 shows, these tasks can and should be delegated to the computer, and to a large extent this is the trend in many companies today. Similarly, and more so, the technical group evaluations of designs has been and is presently performed with the invaluable assistance of computers. These evaluations, though, have been characterized heretofore as being an aggregate of individual participations, without a "systems group" approach; and many times these evaluations have needed more team participation and a repository of common project data.

What is needed is a new design environment that makes possible a symbiotic exploitation of the user's creativity/control and computer/equipment capability in benefit of the total design process. It is firmly believed that a judicious planning and development of IPAD will provide that future design environment.

The major outside appearance of this new environment is illustrated in Figures 3-2 and 3-3, in which the type and number of terminals is tailored to the size of the project. Figure 3-2 depicts what could be an executive room for management/engineering reviews, with the number of terminals floating according to the needs; the minimum configuration will include a single terminal. The wall display systems are controlled from one of the interactive consoles, and the displayed data is accessed directly from the project data bank. The review team is assisted by the data base administrator and support personnel to access the data in their own areas of responsibility and to participate in its review. Three large display screens are shown, although their number will be determined on the basis of need for each organization or project. Peripheral equipment consisting of smaller interactive terminals, printers, etc., will also be available as required. Review team assistants will record minutes of the meeting, identify action items for various tasks, and create temporary files to update the project action and task status files via the data base administrator. The major benefits to be accrued by such a new design environment are summarized at the bottom of Figure 3-2.

Figure 3-3, on the other hand, illustrates what could be called a typical IPAD working room. Interactive terminals, interactive large-screen display systems, minicomputers, printers, and other peripheral equipment are part of this installation, where

DESIGN	ANALYSIS
• Essentially CREATIVE But Requires <u>NON CREATIVE</u>	• Essentially ANALYTICAL Involves Determining the Applicability of Various Mathematical Formulas and Physical Laws But Requires <u>REPETITIVE</u>

REPETITIVE
TASKS

DRAFTING	MATHEMATICAL COMPUTATIONS
TO DEVELOP AND COMMUNICATE IDEAS	TO DEVELOP THE EVALUATION OF IDEAS
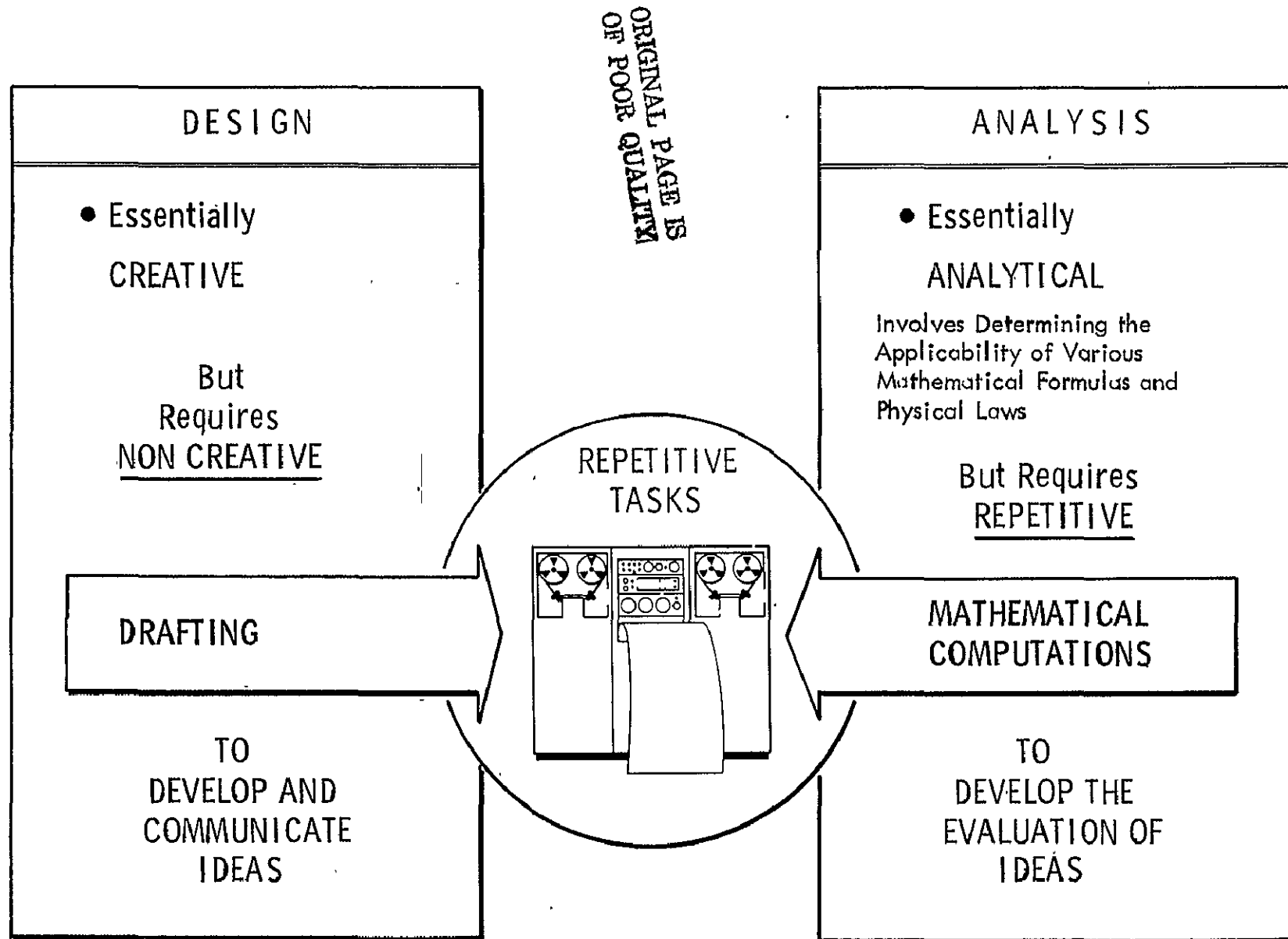
Figure 3-1. The Role of the Computer

DEFINE THREAT
TIME PERIOD
RETALIATORY SYSTEM
SYSTEM REQUIREMENTS
MISSION EQUIPMENT
MISSION PROFILE &
CONSTRAINTS

SYNTHESIS
GEOMETRY
MASS PROPERTIES
AERODYNAMICS
PROPULSION
STRUCTURES
ACCELERATION LIMITS
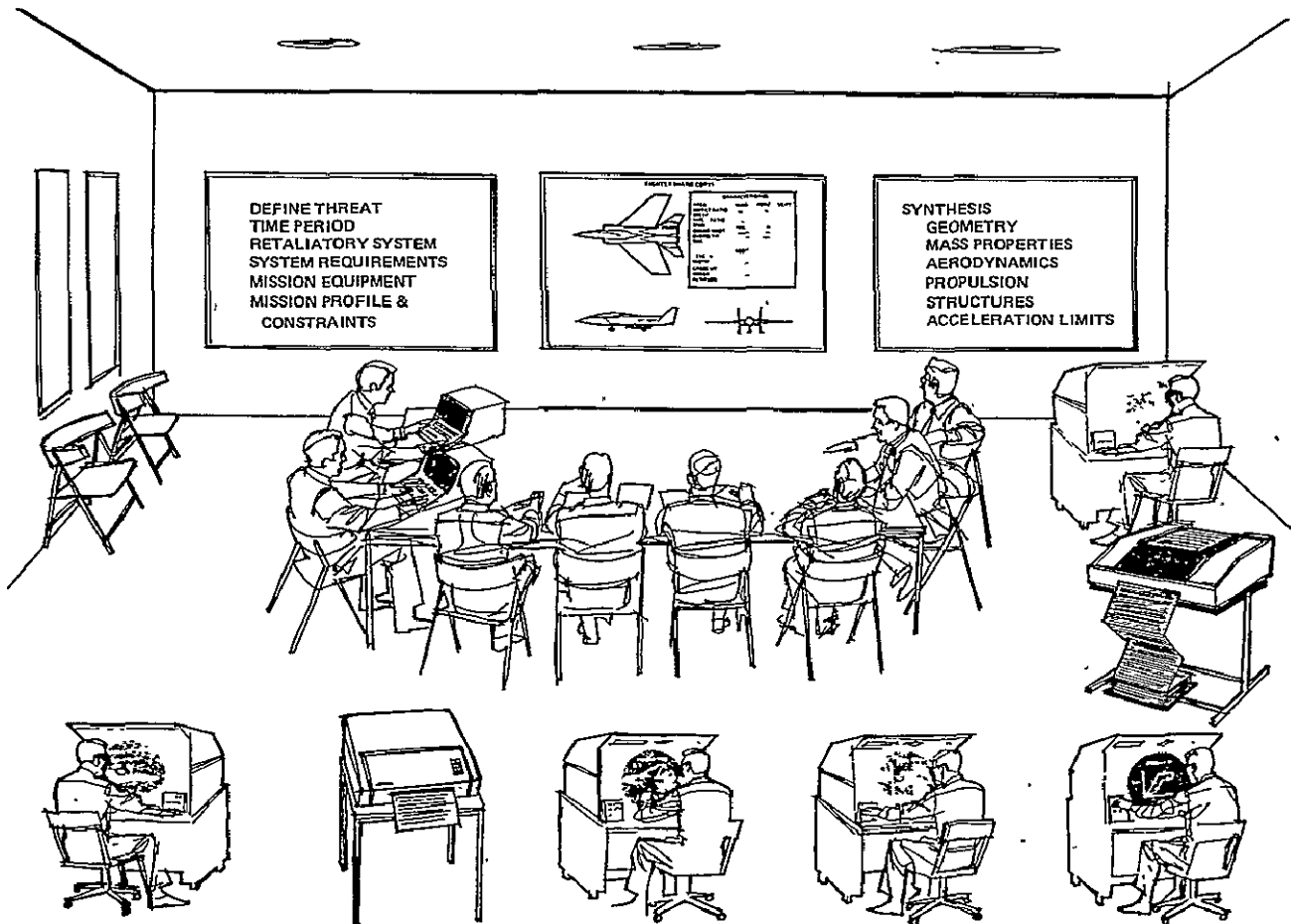
IPAD IMPROVES PRODUCT QUALITY

REDUCES TECHNICAL AND PROGRAMMATIC RISKS
- PROVIDES FOR INCREASED MANAGEMENT PARTICIPATION
- INCREASES COMMUNICATIONS AND DATA DISSEMINATION
- ENHANCES DETECTION OF ERRORS/MISDIRECTION

ENABLES RAPID AND FREQUENT TRADE STUDIES

- BETTER SELECTION OF VIABLE DESIGN ALTERNATES
- QUICKER REJECTION OF DEAD-END APPROACHES

STIMULATES USER'S CREATIVITY
- PROVIDES GREATER VISIBILITY OF COMPLEX RELATIONSHIPS
- MAINTAINS "MENTAL MOMENTUM" (THROUGH RAPID TURNAROUND)
- FEATURES COMPLETE USER CONTROL OF HIS TASK

IPAD CONSERVES RESOURCES

REDUCES CALENDAR TIME
- UP TO 20:1 ON SELECTIVE TASKS
- UP TO 3:1 ON PREDESIGN STUDIES
- UP TO 2:1 ON OVERALL DESIGN PROCESS

REDUCES DIRECT LABOR HOURS AND COMPUTER RUN COSTS
- UP TO 10:1 ON SELECTIVE TASKS
- UP TO 4:1 ON TYPICAL PROJECT

MITIGATES SKILL PROBLEMS ON PROJECTS
- PROVIDES TUTORIAL AND PROMPTING CUES
- PROVIDES AUTOMATED DESIGN ASSISTANCE

FOCUSES DEVELOPMENT OF SOFTWARE (NATIONALLY)
- INTEGRATED, GENERAL-USE ENGINEERING-TOOLS
- MORE EFFICIENT COMPUTING SYSTEMS

Figure 3-2. Future IPAD Design Environment – Executive Room
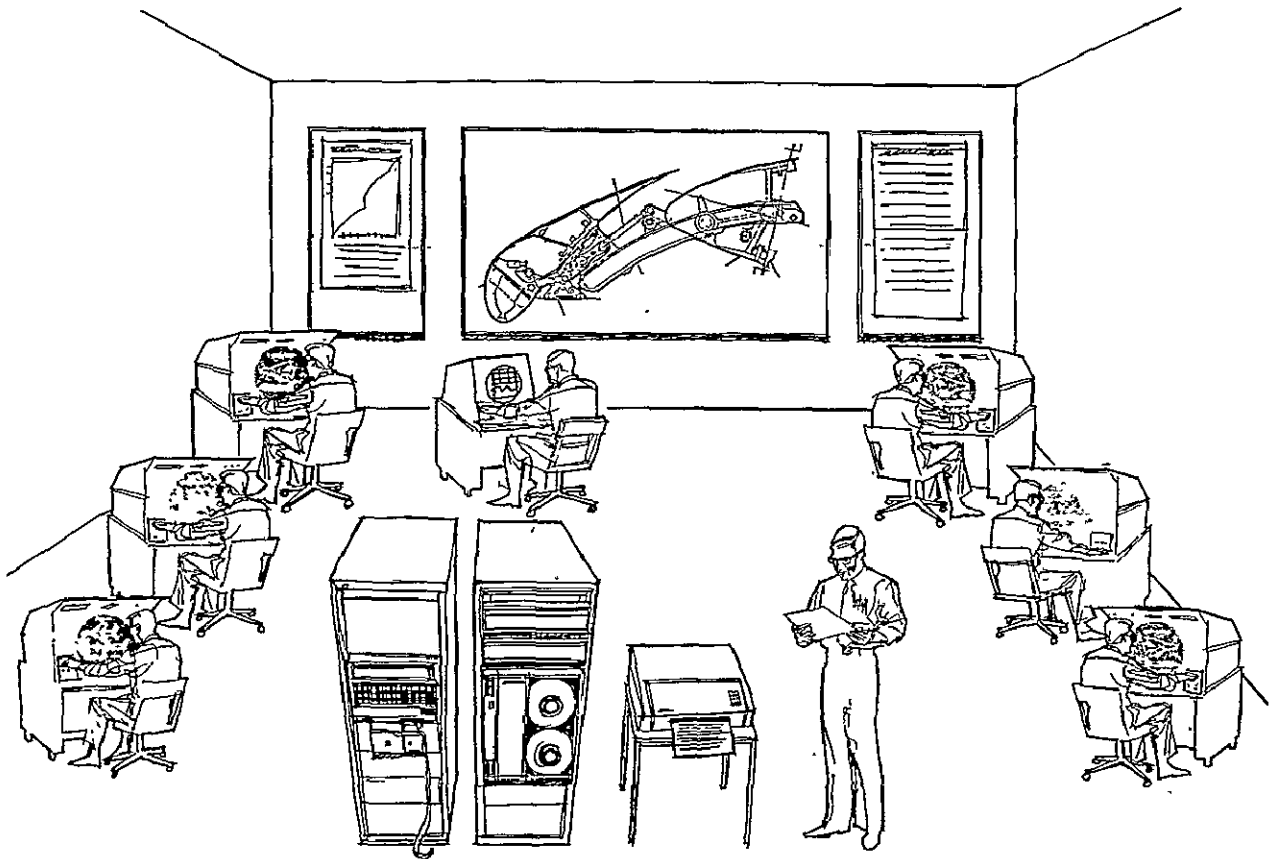
Figure 3-3. IPAD's Future Design Environment - Working Room

creative tasks are being performed. Individual team members access their own disciplinary capabilities in the form of Operational Modules, as well as data libraries, user files, common data banks, general- and special-purpose utilities, etc., as required to perform their individual tasks or in an integrated evaluation involving several users in sequence or parallel. The wall large screen display system shown is a precursor to "electronic board" equipment, which must feature better picture resolution and adaptability to practical design functions. This board is envisioned as a flat bed, interactive device supported by comprehensive design capability software having access to extensive data bases/libraries and user files. These data bases, libraries and files and the design software will permit the designer to create his designs on this interactive board with complete subordination of computer and equipment. A portion of this board would be used as a "scratch pad" to display accessed data from his files (e.g., standard parts, previous designs, yesterday's thoughts, etc.) and then "pick" the complete part drawing, sketch, etc., as a unit and move it to the location where it fits the design. Automatic dimensioning, bill of materials, specifications, etc., will be available from the comprehensive design software and the designer's data bases/libraries.

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This brief description of the future design environment that can be afforded by an IPAD system counts on the imagination of the reader to extrapolate his thoughts and subjectively appraise the tremendous potential such an environment has to offer.

Figure 3-4 illustrates a sequence of design activities as they are typically performed in conceptual and preliminary design activities for an aerospace-vehicle project. The sequence is self explanatory and is one more illustration of the use of the new design environment for multidisciplinary activities.
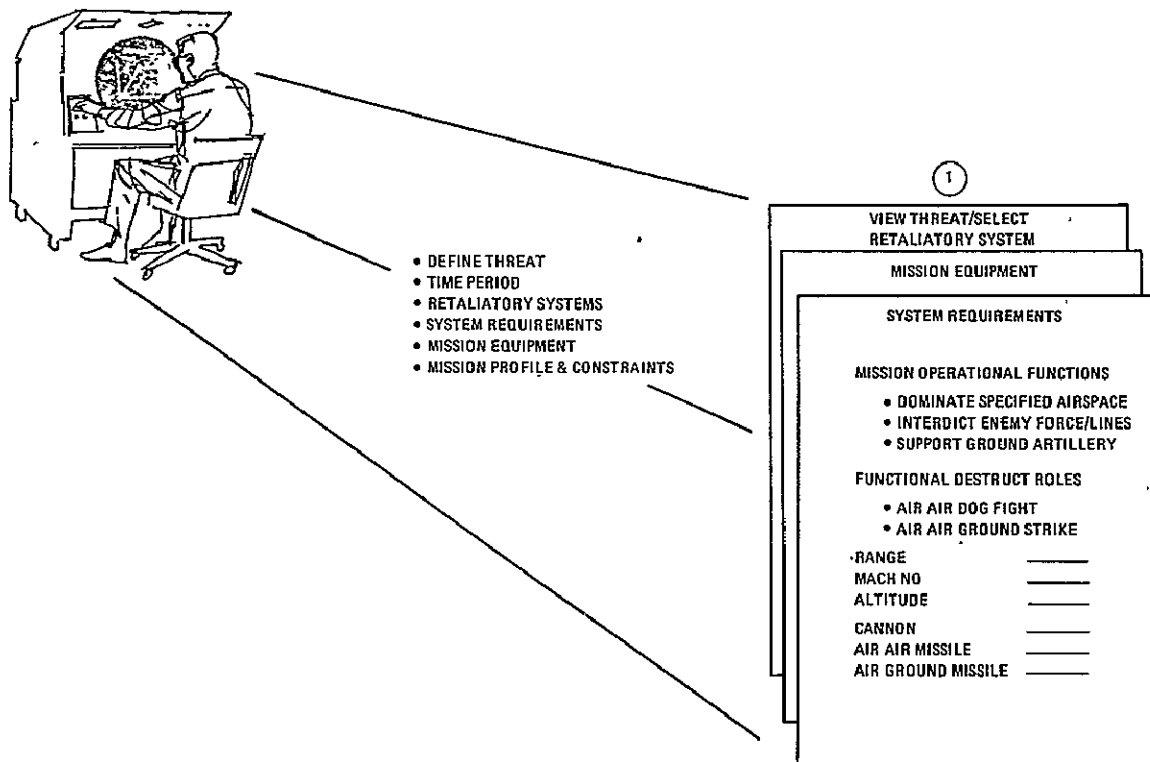
Figure 3-4. Future IPAD Design Environment.
Typical User in Design Sequence

① MISSION DEFINITION
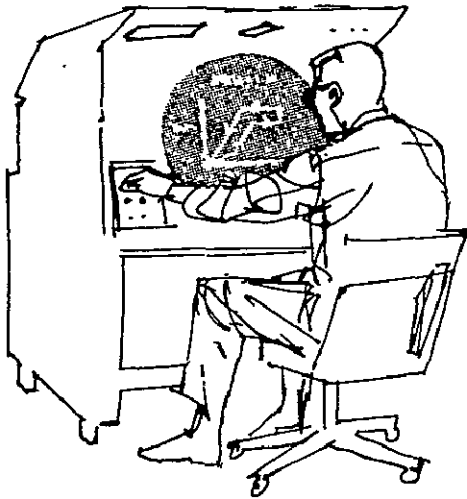
② SELECT CONFIGURATION
  PARAMETERS & SYNTHESIZE
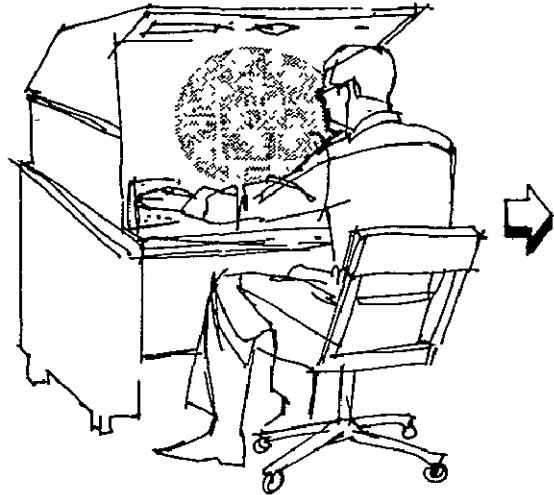
- DEFINE THREAT
- TIME PERIOD
- RETALIATORY SYSTEM
- SYSTEM REQUIREMENTS
- MISSION EQUIPMENT
- MISSION PROFILE & CONSTRAINTS

SYNTHESIS
- GEOMETRY
- MASS PROPERTIES
- AERODYNAMICS
- PROPULSION
- STRUCTURES
- ACCELERATION LIMITS

③ EXTERNAL DESIGN & STATEMENTS

④ INTERNAL CONFIGURATION ARRANGEMENT
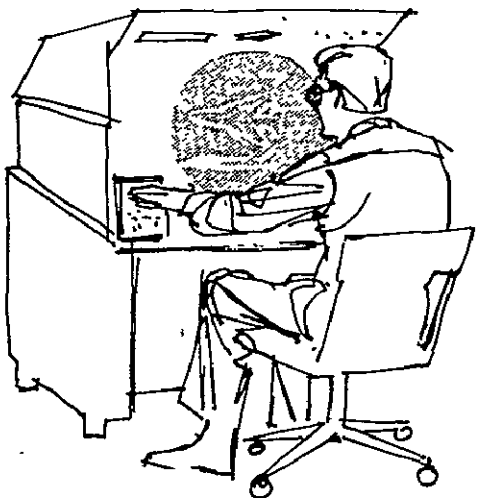
- SIDE VIEW   - SUMMARY
- PLAN VIEW   - WEIGHTS
- FRONT VIEW   - PERFORMANCE
- ISOMETRIC   - MISSION

INSTALL:
- CAPSULE   - WEAPONS
- AVIONICS   - ECS
- ENGINE   - AERO SURFACES
- FUEL   - GEAR

Figure 3-4. Future IPAD Design Environment. Typical User in Design Sequence, Contd

⑤ CHECK BALANCE

⑥ PERFORM TRADE STUDIES
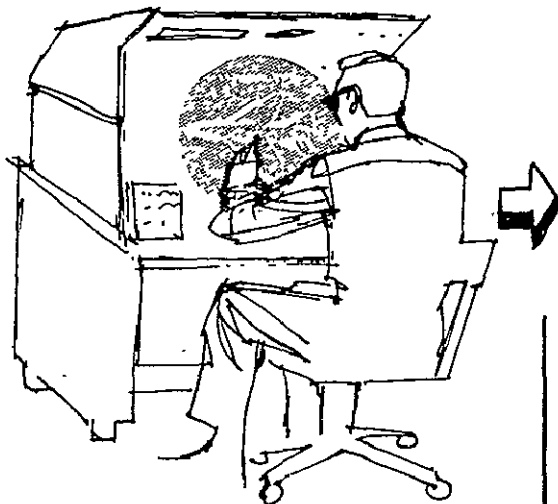
- MOVE WING
- MOVE TAIL
- REARRANGE INTERIOR
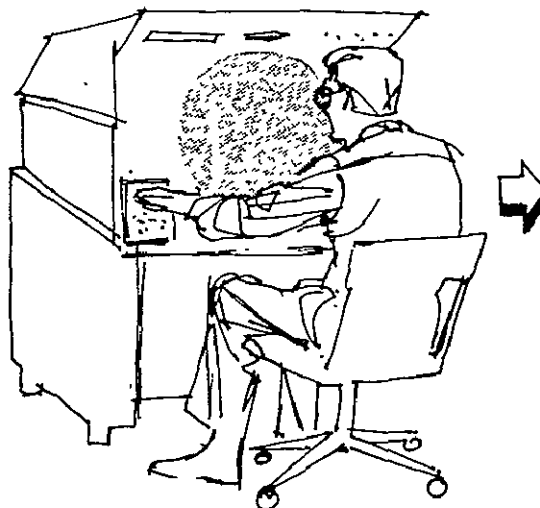
OPTIMIZE CONFIGURATION
DISPLAY GRAPHICALLY

⑦ CONCEPT COMPARISON & SELECTION

⑧ FINAL CONFIGURATION
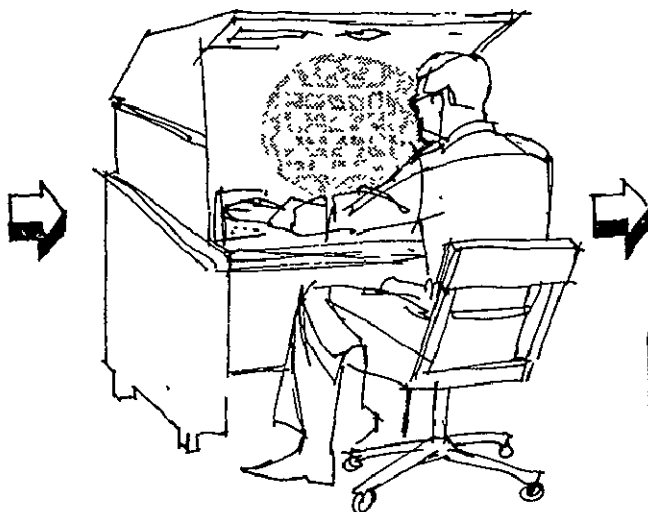
SHOW FOR OPTIMIZED CONCEPTS:
- THREE VIEW
- TABULATED DATA
- BAR CHARTS
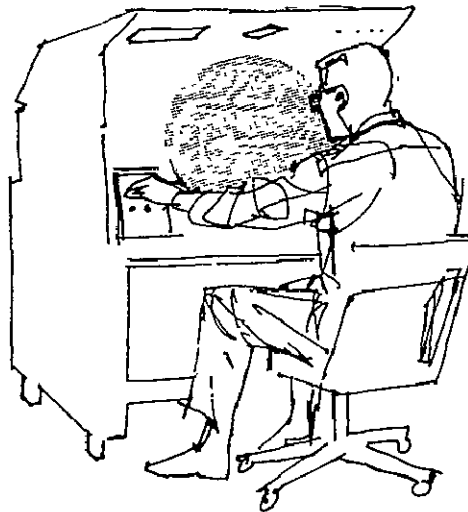
DOCUMENTATION (HARD COPIES)
- THREE VIEW
- WEIGHT DATA
- PERFORMANCE DATA
- MISSION DATA
- GEOMETRY DATA
- TRADE STUDIES

Figure 3-4. Future IPAD Design Environment. Typical User in Design Sequence, Contd
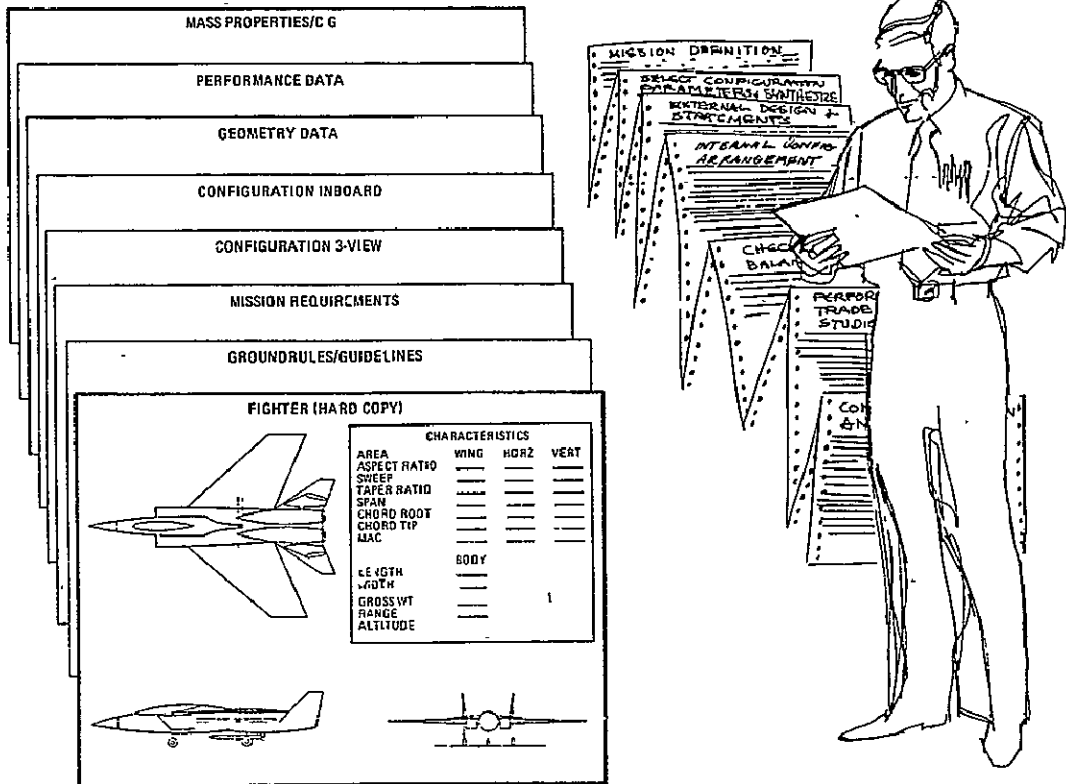
Figure 3-4. Future IPAD Design Environment.
Typical User in Design Sequence, Concluded

4 QUESTIONS AND ANSWERS

This section presents answers to key questions posed in the RFP by NASA in relation to Tasks 1 to 8. Although many aspects of these questions have been answered implicitly or explicitly elsewhere in this report, additional consideration is given to each question individually in the following paragraphs.

4.1 Task 1 - Characterization of the Design Process

4.1.1 What different disciplines should be involved? - The IPAD system, as presently conceived, is receptive to having all disciplines represented in it by means of their respective Operational Modules and appropriate interfaces with Multidisciplinary Data Bank and other Operational Modules. The question should be qualified in terms of discipline involvement in the various phases of the design process and, furthermore, in terms of specific project requirements since no two projects are alike, although similar creative design processes and evaluations may be performed by some disciplines. Since the IPAD System is designed with the required flexibility to accept any set of disciplines with their own degree of sophistication, then the basic issue posed by this question becomes immaterial in the long range. But, if a specific implementation is in mind, such as a First Release Capability for IPAD, then the disciplines and the contents of their Operational Modules should be defined. In this respect, the list of disciplines and the present automated capability described in Section 2.4 of this volume should be considered as the initial goal for IPAD's First Release Capability.

4.1.2 What disciplines are already adequately represented by existing codes? Which ones are missing? - Most of the engineering disciplines (such as aerodynamics, performance, structural analysis, propulsion) have developed, through the years, a wealth of automated procedures ranging from simplified analyses to comprehensive treatment of physical phenomena. Although many specialists can make a justified case for further development, an adequate capability is available in many of these disciplines, in particular for conceptual and preliminary design phases.

On the other hand, design disciplines (such as vehicle configuration and subsystem design) have not had, until recently, the benefits of adequate equipment and software to perform their functions more effectively. Among these are the creative functions, which can hardly be delegated to any equipment or computer, and the routine functions, most of which can and should be automated. By taking the drudgery out of the.design and by providing special equipment and aids, the designer can dedicate his effort and talents to the

more challenging creative activities and contribute to a more effective design process. The design functions are presently underdeveloped and offer a fertile ground for cost-effective automation.

Management is another area in which adequate automated tools are missing. It is envisioned that the general and special purpose utilities offered by IPAD would afford almost instantaneous visibility in all tasks being performed in a given project by accessing files and data stored in the project's Multidisciplinary Data Bank. A series of Operational Modules specifically designed to perform management tasks should be added.

The areas of operations research, reliability, maintainability, safety, logistics, and economics could benefit from the development of additional automated capability.

4.1.3 What disciplines have to be represented primarily by experimental data? - The use of experimental data is commonplace in most of the disciplines involved in aerospace-vehicle design, particularly materials, aerodynamics, stress analysis, weights and several subsystems. The need for experimental data and the basic drivers for generating it will not be changed by IPAD, but the means of reducing, interpreting, curve fitting, and finally applying the data to the design could be substantially improved by the use of interactive equipment and general and special purpose utilities to be available within IPAD.

4.1.4 How should experimental data by handled in the system operation? - Experimental data is usually generated because of lack of appropriate analytical methods to predict behavior under specified environmental conditions, or to identify the environment itself. The number of interacting variables could be large and, typically, many experimental points are required to cover the possible ranges of the variables and the scatter in test results. A large amount of raw data could result from a test program, and it is cumbersome to use it in that form. The raw data is usually interpreted, reduced, and curve-fitted to make it more amenable for use within analytical evaluation procedures. The IPAD system should provide expeditious means of reducing and curve fitting experimental data so that the user does not need to store it in raw form, and therefore save prime storage space.

4.1.5 What aspects of the design are not quantifiable and what impact do they have on design process? - The non-quantifiable aspects of the design are many and form the body of intangibles and artistry that cannot be delegated to a computer. Many design decisions are not quantifiable because they are never brought to the surface for that purpose, and are imbedded in established design practice, availability of stock or parts, experience of the designer, etc. Although the effects of those decisions on the end product could be measured in terms of weight, drag, and costs, their impact on the design process itself is not significant.

4.1.6 <u>What is the proper place and role of statistical information in the system?</u> - Statistical information should be contained in local user's data banks and they should be easily recalled, updated, and categorized. A general-purpose utility (STATUM) is provided by IPAD to help in analyzing, reducing, and applying statistical data in any discipline. The role of statistical information in the system is to be determined by the discipline using it.

4.1.7 <u>What should be the IPAD level of application?</u> - The level of application of IPAD should be progressive, starting with a management/engineering capability for conceptual and preliminary design phases, and gradually expanding to other fields and phases of design as a result of a planned evolution of IPAD and the levels of funding available.

4.1.8 <u>What should be the range of IPAD applications?</u> - A distinction must be made here between IPAD's system software and IPAD's engineering Operational Modules. The system software is applicable to any set of Operational Modules and as such is applicable to any type of vehicle or design project. On the other hand, the engineering software is tailored to the evaluation of specific phenomena, which is very dependent on the type of vehicle or design at hand. The set of Operational Modules and the pertinent automated procedures used for the design and evaluation of an aircraft are different than those required for a ship, or for a bridge. The selection of the appropriate set of Operational Modules should be made to satisfy the most immediate plans of the agencies involved in the development of an IPAD system.

4.1.9 <u>How can one resolve the unavoidable conflict between the level of analysis and computer time? What is the optimal level of analysis at each stage of the design? How can one measure and determine it?</u> - The cost of analysis (computer time and man-hours) is known to increase with the level of analysis, whether due to degree of sophistication and thoroughness or because of evaluation of behaviour under different conditions. The level of analysis to be used in a particular evaluation is determined by specialists in each discipline, and the conflict most frequently is not between the analysis level and the computer time required (they very well know how much it costs), but rather between the cost of the needed analysis and the budget available. It is true that the level of analysis should be in balance with the degree of definition of the product, and unnecessary analysis should be avoided; but a competent design team already has built-in within its modus operandi judicious selections of adequate levels of analysis for each stage of the design. It is doubtful that an optimum level of analysis could be established a priori and, furthermore, that it could be measured. Confidence on the results of a proven procedure may be the deciding factor, or a detailed level of analysis may be justified to substantiate a weight savings that permits meeting minimum performance or payload constraints. A gamut of special situations, even within a single project, can invalidate any preconceived ideas or the statistics of previous cases, so that the selection of the most adequate level of analysis should be left to experienced members of the design team.

4.1.10 <u>What choice of design strategy should be available to the designer in seeking</u> <u>the optimum design? For instance, how can tradeoff data be generated and used to</u> <u>speed up the design process?</u> - Many optimization and suboptimization loops take place in the various phases of design, ranging from overall vehicle sizing to design details such as panel stringer spacing. Most disciplines participate in one type or another of optimization study. Conceptual and preliminary design vehicle synthesis programs have built-in optimization loops, where major configuration and subsystem quantities are the design variables, and the merit functions are measured in terms of overall vehicle performance or in meeting a given set of requirements. Familiar tools such as these must be preserved, and IPAD can further enhance this capability by providing an interactive, general-purpose optimization utility (OPTUM), whereby the user can specify his design variables, constraints, and objective function as well as participate (interactively), if he wishes, in monitoring the progress of the optimization. This same utility can be used as a parameterizer to obtain tradeoff data, either interactively or in a batch mode. The availability of this general-purpose optimization utility will provide the core for all optimization and tradeoff data generation required to speed up the design process, from multidisciplinary studies to local sub-optimization within a single discipline.

4.1.11 <u>How could one judge the efficiency of independently developed codes relative</u> <u>to their efficiency when incorporated into the IPAD framework? At what point would</u> <u>it be more economical to rewrite the independent code before incorporation into IPAD?</u> - The efficiency of a code must be considered in terms of total costs; that is to say, both user and computer-related costs. The involvement of the user in setting up a computer run in the present computing environment is, typically, the largest portion of the problem-solving activity, and as such offers a sizable target for streamlining and cost savings. One means of accomplishing this objective is by interactive graphics (e.g., checking of input and output data, automatic plotting of results, monitoring progress of iterative procedures, etc.). So, the relative efficiency of existing code, as compared when incorporated into IPAD, could be measured in terms of investment required to make it more efficiently usable versus the savings to be accrued during operations. The projected usage rate, of course, is an important factor in this evaluation. On the other hand, there is code efficiency in terms of computer costs. An existing code that was developed to run efficiently in one system does not necessarily run efficiently in all systems. Even the charge algorithm used within a company may dictate changes to reduce the running costs of specific programs, since these algorithms weigh differently the use of central processor, peripheral equipment, tape handling, memory units, etc.

Convair Aerospace has experienced cost savings merely by interfacing two or more programs (unmodified). This improvement was due to (a) avoiding manual handling of input/output, and (b) automatic generation of data from one program to the next.

In conclusion, it is felt that each agency or company using IPAD should develop its own standards as to extent and type of changes that are justified for efficient use of independently developed codes. This statement is made with the understanding that the problem-solving algorithm within the code is not altered.

4.1.12 <u>What set of design variables defines the vehicles to which IPAD is to be applied</u>? - This question suggests the existence within IPAD of specific sets of design variables for one or more type of vehicles. If IPAD were a hardwired multi-disciplinary computer program this could be possibly necessary, but the presently conceived IPAD system is softwired and has the flexibility to accept any set of design variables which are pertinent to any type of vehicle. The specialist employing the optimizer (OPTUM) can select any number of design variables consistent with computer-time constraints. Any other approach will short change the project design teams and detract from wide acceptability of the system.

4.1.13 <u>Should a set of design variables be divided into subsets of basic ones (i.e., wing aspect ratio) and local ones (i.e., skin thickness of a specific panel)</u>? - Experience gained in the use of many vehicle and subsystem iterative redesign processes indicates that the total set of design variables is typically, and conveniently, divided in several subsets according to the stage of design development. During conceptual and early preliminary design phases, most vehicle sizing requirements are met by using basic design variables from various disciplines and there is little need or enough design definition for inclusion of local design variables. In many cases the effects of local design variables are already "built-in" in one or more basic design variables (i.e., unit wing weights including preoptimized structural concept proportions with proper manufacturing constraints) and they are not needed explicitly in the vehicle redesign process. As the design evolves into more detailed phases the need for local design variables increases, but this need usually can be confined to the operational modules peculiar to each discipline. The results of this sub-optimization are usually reflected into basic design variables which typically are kept within the overall vehicle optimization loops.

4.1.14 <u>How should the number of vehicle design variables be reduced to a tractable number</u>? - The number of design variables typically used in conceptual stages is small. They include wing aspect ratio, wing area, wing loading, thickness/chord ratio, body fineness ratio, etc. A larger number is used during preliminary design and a substantially larger number must be considered in detailed design. Typically, in a noncomputerized environment, the detailed design variables are manipulated in groups involving one or more disciplines, and are never considered simultaneously, since it would be a slow and complex process. Automation makes it possible to speed up this process but a large number of design variables is still undesirable. Due to the implicit relationships tying these variables together and the existence of highly

nonlinear and discontinuous functions within each discipline, the mathematical optimization problems associated with a large number of multidisciplinary design variables could be formidable. The number of vehicle design variables must be kept as small as possible while still retaining enough "visibility" for the more strongly interrelated effects. On the other hand, approaches using optimization algorithms with design variable linking schemes and the subdivision of the overall optimization problem into various suboptimization loops (including taking a reduced number of variables at a time) offer some possibilities for efficient vehicle optimization loops. Another means of reducing the number of design variables treated simultaneously is to convert them to parameters which are varied by the responsible specialist from an interactive terminal. In this case, the specialist can use his judgment and experience in directing the vehicle optimization process.

4.2 Design of IPAD System

Key questions posed in the RFP in relation to Task 2 are answered in the following paragraphs:

4.2.1 How should the system be organized to provide sufficient flexibility to accommodate independently developed codes, pre-existing and/or those created in the future ? —
Three organizational systems were evaluated: hardwired, self-organized, and user organized. The first two are relatively inflexible to change and growth. The user organized system is a compromise between the first two approaches, which obtains the sophistication of the self organized system through user interaction yet has the inherent simplicity of the hardwired system. The advantages combine those of the two preceding systems, and in addition the approach is most flexible, highly adaptable to changing conditions, and most easily modified/updated. Since the individual users are responsi ble only for their own Operational Modules, it features the fastest incorporation of modules by a substantial margin and the user is an involved participant in the process. Perhaps surprising, this approach requires the least overall executive software development because the user himself performs many of the executive functions. The use of task control sequences will permit the user to fabricate "execution strings" nearly as automatic as possible within a self-organized system.

4.2.2 What computer languages will be admissible in the pre-existing codes ? — The intent of the user-organized system is to accommodate all codes that will currently execute on the host computer system. Five computer languages are considered as candidates acceptable in IPAD: FORTRAN, ALGOL, JOVIAL, PL/1 and COBOL. In addition, the various assembly languages supported by the host computer will be acceptable.

4.2.3 What degree of machine dependency is acceptable for IPAD? - The machine dependency of IPAD is that of its software elements, some of which are highly dependent on the operating system, while others are almost machine independent. Total machine dependency must be accepted for software such as: the host operating system, the host timesharing subsystem, compilers for programming languages (principally FORTRAN) and for the Data Manipulation Language, a Data Base Management System, and interactive Query Processor. From the executable code for IPAD the EXECutive is very dependent on the machine, while the Special Purpose Utilities are highly transferable, and the General Purpose Utilities will be transferable if written in the proposed General Graphics Language. Transferability of non-executable code can be achieved by the development and implementation of standard languages, as proposed in this study.

4.2.4 To what extent and how should the human element be retained in the system control in order to utilize engineering intuition, judgment, and experience? - The user-organized approach adopted for IPAD ensures user control in the application of IPAD to the design process. The interactive terminals provide for proper interface between the user and the IPAD system mounted on the computer complex. The user performs the creative jobs with the assistance of hardware and software elements provided by IPAD.

4.2.5 What degree of flexibility should be given to the system operator in arranging available Operational Modules into different sequences according to the needs? - In order to become a practical, useful tool, IPAD must provide unlimited flexibility for the user to solve his design/evaluation problems. This capability is provided in the proposed IPAD design by means of Task Control Sequences that the user assembles himself (and freezes for future use).

4.2.6 What I/O devices will best serve IPAD? - Although IPAD can be used in batch mode, it is only under an interactive environment that it can be justified and proven to be cost effective. The most advanced type of interactive terminals are considered best to serve the potentials of IPAD.

4.2.7 What will be the impact of next generation computers on IPAD and its applications? - It is undoubtedly not justifiable to impose on IPAD's development the requirement to accommodate the supercomputers rather than vice-versa. The impact of next-generation computers can be lessened by adopting the following recommendations:

1. Don't explicitly provide for the supercomputers in IPAD's design approach. Let "upward compatibility" of the supercomputer's system software eventually provide the framework for IPAD.

2. Until then, "front-end" the supercomputer with a more sophisticated maxi computer that can delegate candidate tasks. Design IPAD to reside on the maxi computer.

4.2.8 What is the first release capability for IPAD that should be developed for subsequent extension? - The answer to this question is discussed in Section 2.5 of this volume.

4.3 Implementation Plan

This section presents answers to questions posed by NASA in relation to Tasks 3,4, and 5.

4.3.1 Can IPAD be developed by a single organization (company)? - It is highly questionable that IPAD could be developed with the personnel and skill capability available within a single organization. IPAD entails the integration of computing systems technology, engineering users, and new software developments, which call for use of the best know-how available in the country, beyond the boundaries of a single organization.

4.3.2 Is it appropriate or desirable to divide the development work among industry, government, university? Should any one of the three develop it alone? - The answer to the first question is that it is highly desirable to divide development work, although a single integrator should be chosen to assemble, check out, and demonstrate the system. The answer to the second question is no, since a cooperative effort will yield best results by incorporating the specialized know-how available in various agencies.

4.3.3 What problems are associated with the inclusion of proprietary codes and ideas into that development? - It would be unrealistic to think that companies will release proprietary codes and ideas for universal use without proper compensation. The design of IPAD is such that each company can mount its proprietary codes on it to substitute functionally equivalent codes available from other sources. This feature permits a company to use IPAD without making available its proprietary data (or making it available to selected governmental agencies) and should lessen the potential problems in this area.

4.3.4 What are the important economic factors associated with IPAD development and operation relative to : a) an industrial company, b) a government organization, and c) military goals? - A single industrial company probably cannot afford the cost of IPAD development. Furthermore, it probably would not want to commit itself to using IPAD until this system has been proven and is operational. A company could, though, commit a share of its research and development (R&D) activities toward the development of features of IPAD for which it has convincing evidence of potential cost savings and cost-effective operations. As a matter of fact, most aerospace companies are doing this now, although these activities are not integrated nor centralized toward IPAD. As far as R&D commitments, a difference must be made between companies doing most of their business as government contractors and those which operate mainly in the civilian market. Gov-

erment contractors are controlled in the expenditures of their R&D funds while civilian contractors may be able to direct some of their profits toward R&D activities, with no government control. The former must direct their R&D activities toward project-oriented objectives and must justify them by their applicability to programs of interest to various governmental agencies. The latter can plan their R&D efforts without these constraints and can implement programs having direct applicability to their main product lines. In short, it is believed that only an industrial company in prosperous years can possibly afford to develop an IPAD system, investing so to gain an advantage over its competitors and tailoring the system to its specific needs. Under these circumstances a government contractor would have little chance of gaining access to an IPAD system, unless an agency such as NASA develops it as a national capability.

But, why should the government support the development of an IPAD system? The need for many of IPAD's features has been established independently by various aerospace companies. These companies – short of being able to develop a full-fledged IPAD.- are developing software to meet immediate needs under individual funding levels which are both inadequate for total system development and wasteful due to duplication of similar capabilities. Government officials will easily realize that most of the government-supported R&D funding that would be used in developing isolated, company-oriented features of pseudo IPAD systems would implicitly be paid by the government anyway. The acceptance of this situation would shortchange the government, the aerospace community, and it will be wasteful of our national resources. What is needed is a common denominator in these developments to avoid duplication, an amalgamating force (agency) to focus on IPAD as an entity, and a centralized implementation effort with appropriate government and industry participation.

A cooperative effort (or funding) from various governmental agencies offers an attractive approach for the development of the IPAD framework software; which makes the core of IPAD and is usable by all. IPAD would permit achieving military goals more rapidly and economically.

4.3.5 What is the impact of future computers on the development and operation of IPAD? – It is anticipated that the next generation computers will have little effect on the development and operation of IPAD because:

1. IPAD must be developed as soon as possible for installation on current computing installations to accrue immediate payoffs.

2. The supercomputers can be "front-ended" with existing major computing systems that will contain IPAD in residence.

4.3.6 What level of skill will be required of a user of the system? – Considering the human-engineering and user-feature aspects of the proposed IPAD design, it is believed that the level of skill required to operate within IPAD will not be any less nor any greater than that of engineering team members of today. IPAD has been designed to fit and enhance the creativity of present design teams; and to reach this goal, the members will be trained in the use and exploitation of its interactive features from the individual and project team points of view.

4.3.7 What is the level of the skill of the people that may be replaced by the system? – Since many of the repetitive tasks imbedded in the design process can and will be effectively delegated to the computer and automatic equipment, it is envisioned that the level of skill that may be replaced by the systems is that of lower ranks of engineering.

4.3.8 What are the associated tradeoffs of the computer and operator cost versus pay saved, including impact of the design process on calendar time reduction? – The lack of appropriate benchmarks precludes project cost savings in specific terms, although existing evidence points to substantial savings obtained with isolated IPAD-like capabilities, mostly by means of interactive graphics programs. Although the computer execution costs may increase due to additional hardware required, the interactive involvement of the user will undoubtedly result in a shorter time (and cost) for problem solving and design activities; or conversely, it will make possible more thorough evaluations of the main and alternate designs when time and schedule are of the essence.

4.4 IPAD System Benefit Assessment

This section presents answers to questions posed by the NASA and to questions added by the contractor in relation to Task 6.

4.4.1 What tangible evidence do you have that would suggest an IPAD system would improve performance of military aircraft or return on investment of commercial aircraft? – Figures 4-1 to 4-3 and Tables 4-1 and 4-2 in volume VI, which pertain to a military aircraft but which could be equally applicable to a commercial aircraft, illustrate how an IPAD-type operation was used to define an aircraft configuration to perform a specified STOL tactical mission with minimum takeoff gross weight (TOGW). The final design TOGW was 137,450 pounds versus the early design TOGW of 148,200 pounds; here both configurations would perform the mission, but obviously the performance and return on investment of the final design are noticeably better than for the early design. This example also implies that an adequate number of parametric studies must be made to achieve optimum performance with minimum weight, and that the reduction of the number of parametric studies, because of time or cost limitations, can easily result in higher weights than necessary to achieve the same performance requirements.

4.4.2 Given the present engineering work organization, what is the likelihood that engineers will be able to do more creative work when tedious and routine tasks are taken over by IPAD? – Tables 4-2 to 4-4 in Volume VI illustrate typical times saved by using IPAD-type features (e.g., the interactive mode) on three specific studies. Engineers who worked on these studies were asked what they did with the time saved. Their replies were as follows:

1. It enabled them to vary significant parameters over a wider range and thus do a better technical job.

2. It enabled them to do more discrete tasks.

3. It enabled them to perform several tasks in parallel rather than in series.

4. It gave them more time to think and do creative work (e.g., consider alternative design solutions and operational concepts to reduce development and service operation costs).

4.4.3 Will the system bring closer cooperation between the people from different disciplines? With what results? - Detailed answers to these questions can be found in Section 5.5 of this volume.

4.4.4 (Added by contractor) How can IPAD do creative work? - IPAD itself does not do and is not intended to do creative work; IPAD will enhance the performance of design and data generation and manipulation tasks, permitting the user to respond much faster and more economically than heretofore. However, creative work, creative ideas, and esthetic tastes are the drivers behind the user exploiting the IPAD system capability.

4.4.5 (Added by contractor) The aerospace industry got the job done before without IPAD, so why is it needed now? - From the striking of flint to the harnessing of atomic energy, man has explored and utilized many latent forces of nature. He has continually evolved new technology to better exploit those forces and the power of his creativity. In the past few years, man's creativity has imparted momentum to a new technology. Many of its features are already here, have proven themselves cost-effective, and have been accepted as the new ways of performing many design tasks. IPAD will serve as the vehicle for coordinating and integrating the development of such technology, it will prevent duplication of effort and government funding, and it will contribute to the conservation of national resources.

4.5 IPAD System Impact on Company Organization

This section provides answers to questions posed by NASA on the RFP and questions added by the contractor relative to Task 7.

4.5.1 What are the ramifications of traditional company design organizations and procedures relative to the acceptance and utility of IPAD? - Implementation of IPAD requires that top-level management recognize the need for it and specify that it shall be implemented on the company's programs. Initial implementation of IPAD on a going project in engineering for only the conceptual design and preliminary design phases would require extremely modest changes to current organizations and modest changes to existing design procedures and practices.

4.5.2 <u>How will company design organizations likely change to use IPAD most effec-</u><u>tively?</u> - Near-term changes in organization for an initial IPAD would be very modest and relate mostly to project organizations. These changes include the addition of a Data Base Administrator, the use of automated management techniques to interface with quicker engineering evaluation cycles, and the training of project personnel in the use of IPAD. Further expansion of IPAD would be evolutionary, so that distant-term changes to organizational structure cannot be predicted accurately; however, conjectures on some possible distant-term changes include the possibility of creating "system groups" to replace several closely related disciplinary groups, the elimination of detail drawing and loft boards, the elimination of certain levels of supervision, and the shifting of task responsibilities from one group to another.

4.5.3 <u>(Added by contractor, since it has been raised a number of times during the</u><u>IPAD study) What happens if IPAD is not implemented?</u> - It is believed that IPAD-type systems will evolve very slowly to satisfy individual company/agency needs and without proper integration. A manifold duplication of individual company efforts will result in extra costs, which can be avoided by an integrated approach.

4.6 IPAD Spinoff Assessment

This section presents answers to questions posed by NASA in relation to Task 8 and questions added by the contractor.

4.6.1 <u>Will experience gained in the implementation of a system like this open the way</u><u>to the creation of similar interdisciplinary systems in non-aerospace fields?</u> - Yes. Although there are exceptions, most non-aerospace fields deal with design and operational problems which are interdisciplinary. These problems are typically broken down and solved as single-discipline subproblems. The experience to be gained with IPAD in multidisciplinary aerospace field applications will be an example for other technical and non-technical fields. The IPAD system framework developed for the aerospace industry can be used directly by many other technical/scientific fields utilizing their own Operational Modules.

4.6.2 <u>What are these fields?</u> - Some of the technical and business fields are noted in Section 5.7 of this volume.

4.6.3 <u>(Added by contractor). How rapidly can one expect to have IPAD-type systems</u><u>applied to non-aerospace fields?</u> - Non-aerospace industries that handle large volumes of data and that can exploit automation and an interactive environment will be immediate beneficiaries of an IPAD system. Some government agencies, such as the U.S. Navy, are presently developing IPAD-like systems to fit their specific needs in ship design. Foreign and domestic car manufacturers are using various features of IPAD-type systems that have been developed within the constraints of present equipment and software. The need to reduce costs will be the stimulant to entice "late starters" to adopt IPAD-type systems to streamline their operations.

5. TASK SUMMARIES

This chapter presents summaries of each of the feasibility study tasks reported in detail in Volumes II to VI of this report.

5.1 Characterization of IPAD System

This section summarizes the results of Task 1. A more detailed discussion can be found in Volumes II and III of this report.

The major objective of Task 1 was to establish the extent to which an IPAD System is to support the design process. This objective was pursued by investigating the basic functions performed by various engineering disciplines involved in aircraft design, by segregating their present capability in terms of automated and hand-performed procedures, and by identifying areas for further developments needed to operate within an IPAD environment. The design of an aerospace vehicle is a complex process, requiring the intervention of many specialized disciplines that define the myriad of details that make a product perform successfully. To have considered all aspects of the design process within this feasibility study was judged both unnecessary and unwarranted. Unnecessary, because the objectives of this study could be met by looking into the design process through a "window", provided it afforded enough insight to depict the detailed engineering functions that must be performed, and provided it enabled definition of the computer system size and equipment required to handle the whole design process. Unwarranted, because it would have led to "more-of-the-same" type of information without a real return in investment. The engineering window selected for this feasibility study consisted of the following disciplines: Configuration Design, Aerodynamics, Performance, Propulsion Mass Properties, Flight Contol and Stability, Operations Research, Reliability, Economic Analysis, Structural Loads, Structural Analysis/ Synthesis, Structural Dynamics, Thermal Analysis, and various Subsystem Designs. The design/engineering disciplines included in this "feasibility window" and their respective functions within the design process are detailed in Section 3 of Volume II.

The approach followed to characterize the IPAD System from the engineering user point of view is discussed in the following two subsections.

5.1.1 Design phases. - The aircraft design process is typically divided into various phases or levels of design. Some aerospace companies use conceptual, preliminary, and detailed design phases,while others further break down these basic phases into additional levels. Furthermore, each of these phases is not precisely defined and the division lines vary among companies. The moral behind this existing situation is that

semantics does not design aircraft and that the real backbone of the design process lies in the engineering functions or processes that must be performed from conception to operational use of an aircraft.

In this study, emphasis has been put in identifying grass-root design/engineering functions, their logical place and sequencing in the total process, and their intercommunication needs. Because of this, all partitions of the design process become immaterial and the choice of one or another phase breakdown can be made on the basis of convenience or accepted practice within a company, without affecting the design process itself. With the foregoing considerations in mind the design process was divided into conceptual, preliminary, and detailed design phases.

Flow charts providing the insight needed for this study were prepared to show the various disciplines participating in conceptual and preliminary design tasks, identify the methodology used in performing the tasks, and outline the major flow and sequencing of activities. These flow charts present an overall view of the design process as well as a proper cross referencing for "telescoping" into each discipline's task to find out the type of input data required, details on the methodology used, output of the task, and recipients of the end results obtained. Many of the disciplinary functions are also performed during the detailed design phase, although using more detailed input data and interfacing with a larger number of disciplines. The basic function per se· is the same, and the identification of additional detail was judged unnecessary for the purposes of this study.

5.1.2 ·Engineering creative/evaluating procedures (CEP). - In order to participate in the design process, an engineering discipline, in general, needs input data originating outside and/or within the discipline, ·which is used with CEPs (executed by hand/brain, computerized, or a mixture of them) to generate output data, which is used by other disciplines downstream in the overall design process. A CEP is defined herein as a sequence of steps, the execution of which will either define part of a product, or generate additional data for use in other CEPs, or yield a measure of goodness, or permit one to reach a conclusion or make a decision. Typical examples of CEPs are the sequences of steps required to: create a configuration design; perform a flutter analy-- sis, a performance analysis, or an engine selection; make a weighted comparison of· alternate designs; estimate the cost of a part; etc. The CEPs must be appropriate and sufficient for the immediate design definition goals at a given point in the design process to avoid both underkill and overkill. The type and amount of data associated with the input and output of a given CEP is very dependent on its complexity and relationship to other disciplines. As the design evolves, the degree of participation of a discipline changes from phase-to-phase and involves many CEPs. Also, the amount of data expands and flows in many directions.

A series of functional flow charts were developed to properly identify and record the degree of participation of the disciplines considered in this feasibility study and the type of data required in the design process. The functional CEP flow charts and engineering capability have been extracted from present "modus operandi" of the respective disciplines at Convair Aerospace, San Diego and Fort Worth Operations, and as such are partially representative of the total capability available in each area. For the purposes of this feasibility study, they collectively define the "engineering window" used to assess the major ingredients that enter into the conceptual, preliminary, and detailed phases of an aircraft design process. Although this window was limited in scope, it has provided a more than adequate measure of the degree of involvement of key design/engineering activities, their respective interface, and has helped in defining the size and magnitude of data banks and requirements for computer hardware and associated equipment.

5.2 Design of IPAD System

This section summarizes the results of Task 2 reported in detail in Volumes IV and V of this report.

The major objective of Task 2 was to identify the software elements and hardware equipment required for an IPAD system. This objective was pursued by evolving a conceptual design, conducting a potential user survey, projecting work loads for various types of interactive terminals, comparing various features of major host computing systems, and finally selecting target systems and identifying the various elements of software and language development required for IPAD.

5.2.1 IPAD in relation to host computing system. - Several options were evaluated on how to incorporate IPAD into the host computer complex. System and subsystem levels of dependency were compared, resulting in the recommendation of a subsystem-level approach as shown in Figure 5-1. This figure presents an overview of the host operating system, with IPAD designed subordinate to its subsystems; i.e., an IPAD job is executed like a standard job operating within the framework of the host computing system. This approach requires that the host operating system be highly capable, since IPAD has divested itself of all host system functions. Subordinating IPAD to · the interactive communications subsystem means that there will be variations in IPAD system operation between installations of different computer manufacturers.

Figure 5-1 further illustrates a dedicated minicomputer for users of the General Design Module and refreshed CRT terminals. The principal advantage accrues directly to those users operating through the minicomputer; viz:, faster response time since many interactive functions will be local to the dedicated minicomputer (perhaps shared by several interactive terminals) and hence accomplished without resorting to the host computer. Since these functions will no longer require the host computer,
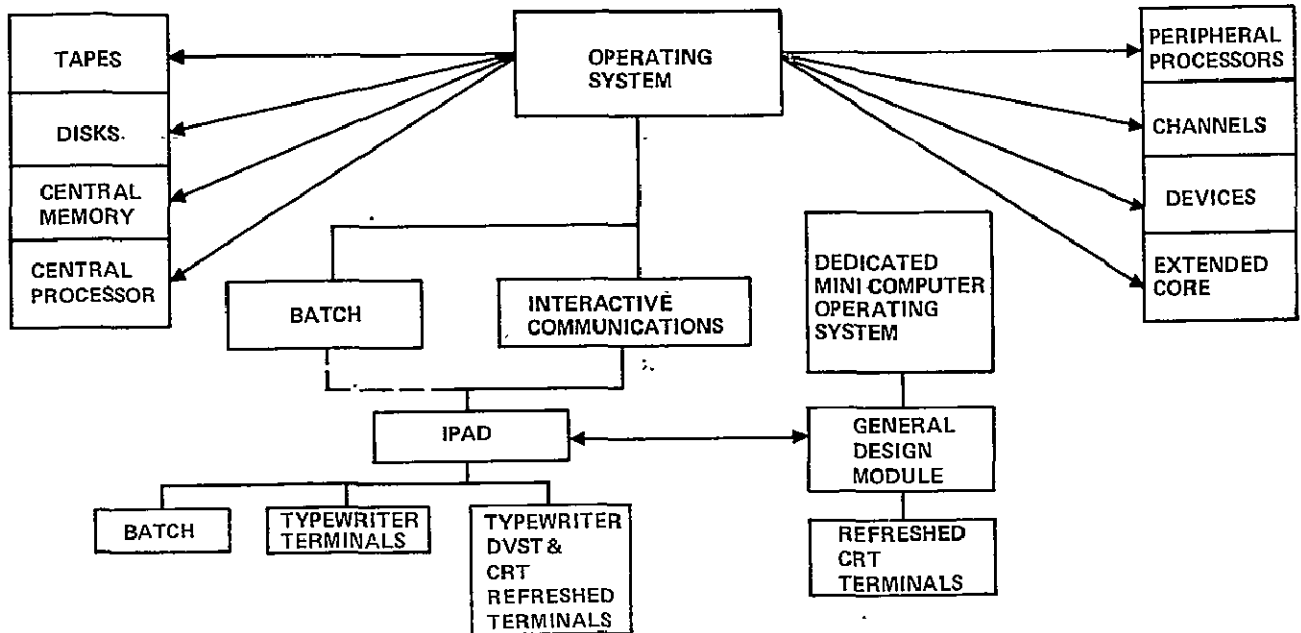
Figure 5-1. IPAD in Relation to Host Operating System

the host operating system will be able to ˉ ːvice the other users more efficiently. Further, the IPAD system software can be split between that residing on the host system and that residing on the minicomputer. This will result in the least impact on the host operating system since it is only the IPAD software on the minicomputer, which requires the interactive communications subsystem with very high data transfer rates (e.g., 40,800 baud). This split will provide a well-defined interface between the host and minicomputer IPAD system software. The disadvantages are that it requires additional hardware to utilize the highly capable refreshed CRT terminals and additional software development to provide the IPAD systems for the dedicated minicomputer. The problems of addressing several target minicomputing systems, although not as severe, parallel those for host computing systems.

However, not every institution intending to use IPAD may be willing to provide the dedicated minicomputers with their attendant identifiable costs. An alternative approach is to provide an IPAD system which optionally utilizes minicomputers for the refreshed CRTs; this necessitates that the IPAD system on the host be able to (optionally) service the refreshed CRTs thus effectively eliminating some of the advantages discussed above, which would now accrue only to those users at those institutions employing the optional minicomputers.

The main user and computing system features that led to the adoption of the design approach shown in Figure 5-1 are:

1. Least competition for resources since IPAD looks like a standard job to either the batch or interactive-communications subsystems.

2. Minimal software development since existing system software is being fully exploited.

3. Least hardware/software dependency since the bulk of IPAD is interfaced (buffered) through the host operating system.

4. Least impact on operating system — IPAD looks like a standard job.

5. Potentially longest life since, being a "standard" job, IPAD will continue to be supported far into the future, possibly until standard host operating systems themselves offer all the advantages accrued through IPAD.

6. Continuous upgrading of IPAD through obtaining (practically) gratis the host system's latest features, including those of all of its subsystems.

7. Fast response time for users of the General Design Module.

8. Cleanest interface between IPAD software elements for host and minicomputer systems.

5.2.2 Computer software for IPAD. - A summary of the required software elements is given in Sections 2.3 and 2.5 and are also illustrated in Figure 2-3 of this volume. The reader is referred back to these sections for details. A graphical representation of IPAD software that emphasizes the wealth of existing engineering software versus that required for development of IPAD is given in Figure 5-2.

5.2.3 Host computer hardware for IPAD. - Figure 5-3 summarizes the hardware requirements and major computing system candidates that have operational equipment suitable for IPAD.

5.2.4 Interactive terminals for IPAD. - Figure 5-4 summarizes the characteristics of several direct-view storage tube (DVST) and refreshed cathode ray tube (CRT) terminals. These terminals are of the most capable type presently available in the market.
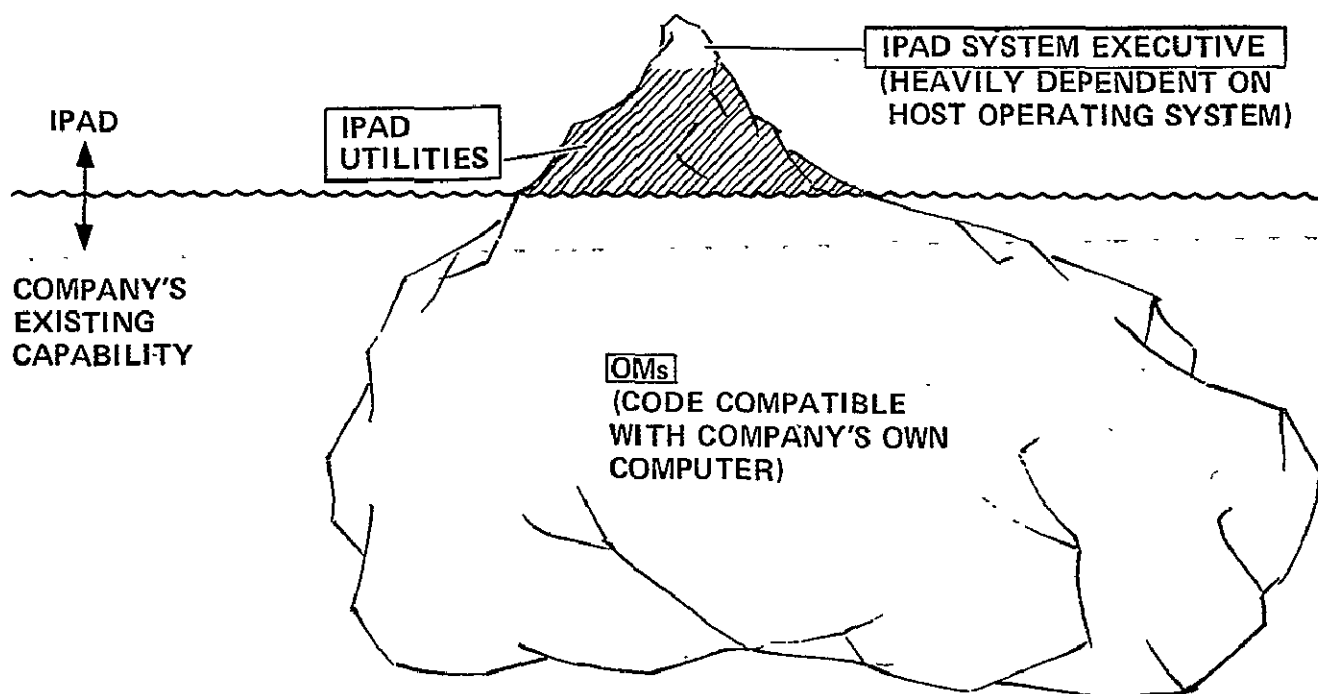
Figure 5-2. Software Iceberg of a Fully Implemented IPAD System

MINIMUM REQUIREMENTS

● MAIN FRAME HARDWARE

MAJOR MEMORY CYCLE	$\leqslant 1.0 \mu S$
TYPICAL BINARY FLOATING ADD	$\leqslant 1.5 \mu S$
CENTRAL MEMORY SIZE*	$\geqslant 100,000$ SINGLE PRECISION "WORDS"
JOB ROLLIN/ROLLOUT OR SWAPIN/SWAPOUT	"PAGING" HIGH-SPEED TRANSFER TO EXTERNAL (LOW-SPEED) CORE

● PERIPHERAL HARDWARE

MASS STORAGE CAPACITY	> 150M SINGLE PRECISION "WORDS"
MASS STORAGE TRANSFER RATE	> 1M CHARACTERS PER SEC.
MAGNETIC TAPE UNITS	> 3
CARD READER/PUNCH	1
HIGH-SPEED PRINTERS	1
MICROFILM RECORDER	1 (CAN BE REMOTE)
TERMINALS (WITH HARDCOPIERS)	26 DVST & 10 REFRESHED CRTs
PAPER TAPE READER/PUNCH, FLAT-BED PLOTTERS	AS REQUIRED

CANDIDATES (ALL ARE LARGE-SCALE SCIENTIFIC COMPUTERS)

IBM	CDC.	UNIVAC	HONEYWELL	BURROUGHS
370/145	CYBER 70 SERIES	1108	6000/6030/6040	B6500
370/155,158	EXCEPT MODEL.76	1110	6000/6050/6060	B6700
370/165,168	(VIZ, CDC 6000 SERIES)		6000/6070/6080	B7700

*IPAD WILL INCREASE CENTRAL MEMORY RESIDENCY

Figure 5-3. Host Computer Hardware for IPAD, Single Project

MANUFACTURER	CDC	CDC	IBM	VECTOR GENERAL	IMLAC	TEKTRONIX
MODEL	274	GPGT	2250	3D2	PDS-1	4002A
TYPE OF CRT	REFRESHED	REFRESHED	REFRESHED	REFRESHED	REFRESHED/DVST*	DVST
SCREEN SIZE (IN.)	20'	20	12 x 12	13 x 14	7.5 x 8.5	7.5 x 5.5
SHAPE	CIRCULAR	CIRCULAR	SQUARE	RECT.	RECT.	RECT.
RASTER X RASTER	4,096 x 4,096	4,096 x 4,096	1,024 x 1,024	4,096 x 4,096	1,024 x 1,024	1,024 x 760
INTERACTIVE TOOLS						
A/N KEYBOARD	X	X	X	X	X	X
LIGHT PEN	X	X	X	X	X	
JOY STICK, MOUSE, ETC.				X	X	X
ANALOG TABLET				X	X	X
FUNCTION KEYBOARD	X	X	X	X	X	X
MINICOMPUTER	CDC 1700	CDC SC1700	NONE	PDP-11, VARIAN 620, ETC.	BUILT IN	NONE

* DVST = DIRECT VIEW STORAGE TUBE

Figure 5-4. Interactive Terminals Suitable for IPAD

In addition to these terminals, large-screen interactive display systems, as illustrated in chapter 3 of this volume, are available and should be a part of the equipment used for the future IPAD design environment. Furthermore, these large-screen interactive display units are considered precursors to the "electronic design board" identified in Volume II of this report as a desirable tool for the interactive General Design Module.

5.2.5 Language development. - The IPAD design approach presented elsewhere in this report emphasizes exploitation of software provided by computer system manufacturers. The supporting software is general in that:

1. It is not developed specifically for IPAD, and

2. With each supporting subsystem, languages exist to provide the capabilities of the subsystem to the users.

Realistically, the languages developed by the general software builders should not be expected to relate directly to IPAD. The development required in support of IPAD is a development of languages (and functional support to these languages) to exploit capabilities of manufacturer supplied software. The objectives of this language development are:

1. To provide, all through a concise lexicon, the full range of capabilities of:

a. The operating system,

b. The timesharing subsystem,

c. The Data Base Management subsystem, and

d. The interactive graphics subsystem.

2. To produce language standards (eventually to become industry standards) for increased portability.

The language development tasks with respect to the four items in 1 above include:

1. IPAD Control Language to interface between the user and the operating system/ timesharing subsystem.

2. Data Description Languages to define data structures and relationships that exist in the data base and those required by Operational Modules and utilities.

3. Data Manipulation Language, which provides the procedural interface between specific Operational Modules/utilities and the data base via the Data Base Management System.

4. Query Processor Language, which provides the interactive procedural interface between any IPAD user and the data base via the Query Processor operating though the Data Base Management System.

5. General Graphics Library, which provides interface between Operational Modules/utilities and the interactive graphics subsystem.

5.3 IPAD System Implementation Schedule and Costs

This section summarizes the results of Task 3, IPAD Implementation Schedule, and Task 4, IPAD System Development Cost, of the IPAD Feasibility Study reported in Volume VI of this report.

Implementation schedule and costs discussed herein refer to the IPAD System components shown in the three left-most boxes in Figure 2-1. A breakdown of these components into elements and subelements of software is shown in Figure 2-3, which is also a summary of the pieces of software required for IPAD (as identified in other volumes of this report).

The general philsophy used in preparing this implementation plan can be summarized as follows.

1. The implementation of all major software components shall be blended in a progressive release, which evolves from demonstration cases into a Pre-Release Capability (PRC) of individual subsystems, a First Release Capability (FRC) for Operating System No. 1 and, finally, deployment of IPAD to other operating systems.

2. The FRC shall be a properly checked out and demonstrated working tool with management and engineering capability for comprehensive design and evaluation studies of an aerospace-vehicle project.

3. Competitive and sole-source participation shall be given to industry and institutions of higher education with the objective of bringing the best available know-how to bear on the design and implementation of IPAD.

4. The major IPAD contractor and integrator shall implement IPAD in one operating system (herein designated System No. 1) first and two other major aerospace companies shall implement IPAD in Operating Systems No. 2 and No. 3, respectively. The deployment of IPAD to additional operating systems could be made in parallel or sequentially with this effort, but is not included in the baseline implementation plan.

5. The emphasis shall be in the development of the new IPAD framework and operating system software rather than in the development of new management/ engineering capability. Substantial automated capability exists in the latter, with exception of configuration and subsystem design/drafting, which needs only refurbishing to absorb the various new features of the IPAD system. The total software package for IPAD demonstration, however, shall contain all required elements properly interfaced to enable an engineering project team to perform a comprehensive aerospace-vehicle design and evaluation study.

5.3.1 Assumptions and groundrules. - Several general assumptions were made at the onset of Tasks 3 and 4 concerning the time frame, funding, and desirable features for IPAD development. These included:

1. Go-ahead was assumed to be in fiscal year (FY) 1975.

2. FY 1974 funds will be made available to support selected key pre-IPAD technology developments that represent critical items the implementation plan cannot realistically ignore. An alternative plan must be provided for the FY 1974 tasks in case these are not approved.

3. The IPAD implementation plan must produce a PRC as soon as possible and a functional FRC within four years from go-ahead.

4. The implementation schedule must provide convenient demarcations for systems reviews prior to the commitment of a large block of funds.

In reference to both schedules and costs:

5. The implementation plan must include a visible risk assessment.

With respect to the end product to be implemented:

6. With due regard for cost and risk, the best designer/fabricator must be selected for any elements of software that can logically and realistically be developed separately.

7. It is a primary objective to bring about software which is both portable and "self-maintaining" to the extent practicable. Codes supplied by each computer manufacturer (e.g., and ANSI standard FORTRAN compiler) can be considered to meet this objective. Since the manufacturer develop and maintains it, it is - in this regard - self maintaining. However, the portable-code objective will be waived wherever the code is required to interface closely with the host operating system or wherever maximum efficiency is required. In this case, a code module will be tailored to a specific computing system, resulting in a functionally identical code module for each computing system accepting IPAD.

8. Development of new management/engineering software shall continue to be funded from conventional technology development studies at large and shall not be included in the development costs for IPAD.

5.3.2 Baseline schedule and cost summary chart. - Figure 5-5 summarizes schedules and costs for the Baseline Implementation Plan. Detailed backup data for the various lines of this chart is given in Section 2 of Volume VI.

As indicated in Figure 5-5 , the Baseline Implementation Plan is divided in two phases. Phase I is concerned with developing IPAD for a single computer operating system, but including portability to all three major operating systems for many software elements as shown by asterisks. Phase I culminates with a demonstration of the FRC for Operating System No. 1 at 45 months from go-ahead and final documentation at 50 months. Development costs of Phase I are estimated at 1385 man-months and 670 computer hours. Phase I is performed under a major IPAD contractor and integrator with subcontracted studies to industry and other institutions on a competitive or sole-source basis as discussed in Volume VI, Section 2.

Phase II is for the deployment of IPAD to two other major operating systems, using all common and portable elements of software developed in Phase I. It is performed by the major IPAD contractor mainly as integrator of two development studies subcontracted to aerospace companies on a competitive basis. This phase produces

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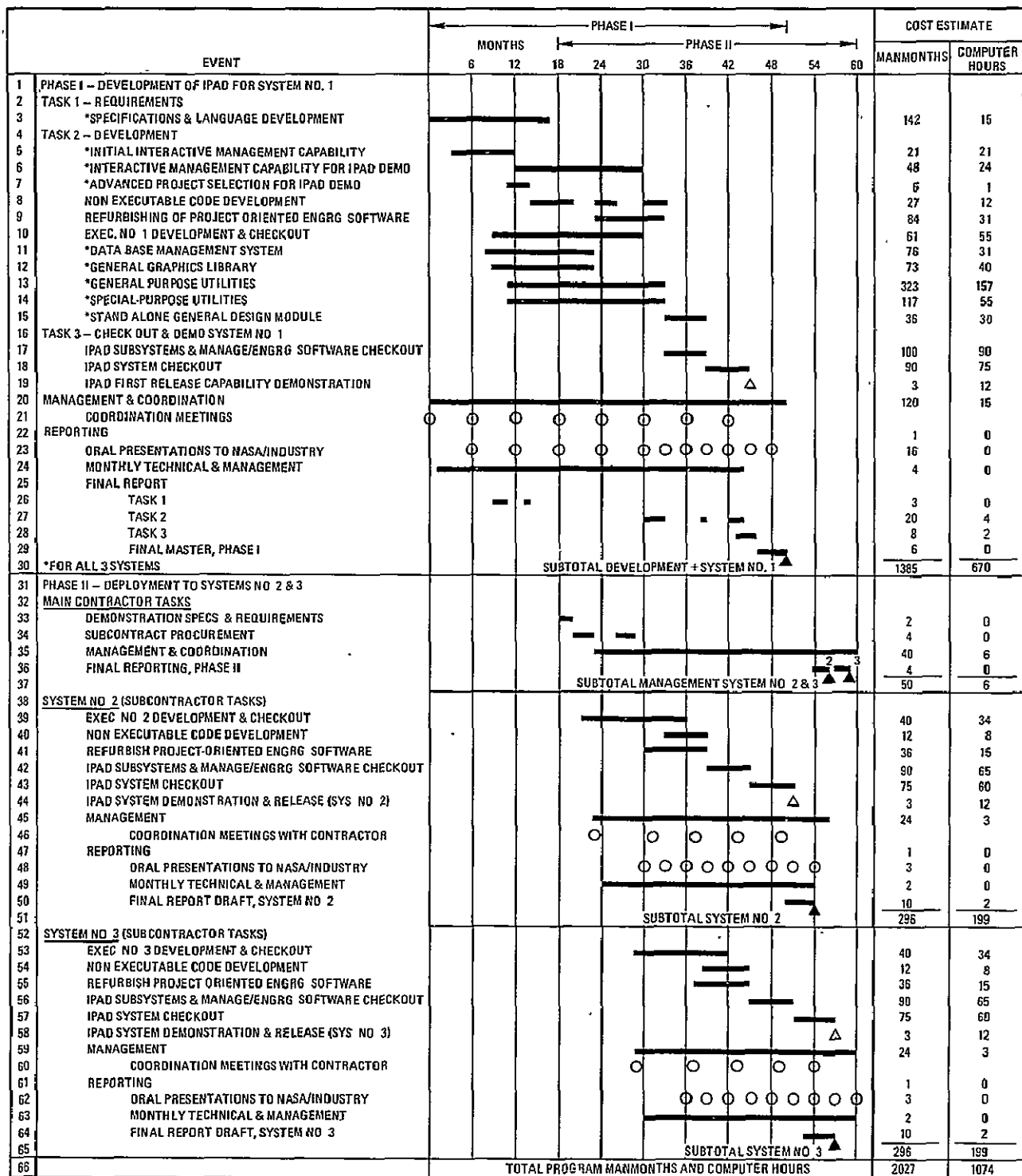| #	EVENT	PHASE I / PHASE II (MONTHS 6-60)	MANMONTHS	COMPUTER HOURS
1	PHASE I — DEVELOPMENT OF IPAD FOR SYSTEM NO. 1			
2	TASK 1 — REQUIREMENTS			
3	*SPECIFICATIONS & LANGUAGE DEVELOPMENT		142	15
4	TASK 2 — DEVELOPMENT			
5	*INITIAL INTERACTIVE MANAGEMENT CAPABILITY		21	21
6	*INTERACTIVE MANAGEMENT CAPABILITY FOR IPAD DEMO		48	24
7	*ADVANCED PROJECT SELECTION FOR IPAD DEMO		6	1
8	NON EXECUTABLE CODE DEVELOPMENT		27	12
9	REFURBISHING OF PROJECT ORIENTED ENGRG SOFTWARE		84	31
10	EXEC. NO 1 DEVELOPMENT & CHECKOUT		61	55
11	*DATA BASE MANAGEMENT SYSTEM		76	31
12	*GENERAL GRAPHICS LIBRARY		73	40
13	*GENERAL PURPOSE UTILITIES		323	157
14	*SPECIAL-PURPOSE UTILITIES		117	55
15	*STAND ALONE GENERAL DESIGN MODULE		36	30
16	TASK 3 — CHECK OUT & DEMO SYSTEM NO 1			
17	IPAD SUBSYSTEMS & MANAGE/ENGRG SOFTWARE CHECKOUT		100	90
18	IPAD SYSTEM CHECKOUT		90	75
19	IPAD FIRST RELEASE CAPABILITY DEMONSTRATION	△	3	12
20	MANAGEMENT & COORDINATION		120	15
21	COORDINATION MEETINGS			
22	REPORTING		1	0
23	ORAL PRESENTATIONS TO NASA/INDUSTRY		16	0
24	MONTHLY TECHNICAL & MANAGEMENT		4	0
25	FINAL REPORT			
26	TASK 1		3	0
27	TASK 2		20	4
28	TASK 3		8	2
29	FINAL MASTER, PHASE I		6	0
30	*FOR ALL 3 SYSTEMS	SUBTOTAL DEVELOPMENT + SYSTEM NO. 1 ▲	1385	670
31	PHASE II — DEPLOYMENT TO SYSTEMS NO 2 & 3			
32	MAIN CONTRACTOR TASKS			
33	DEMONSTRATION SPECS & REQUIREMENTS		2	0
34	SUBCONTRACT PROCUREMENT		4	0
35	MANAGEMENT & COORDINATION		40	6
36	FINAL REPORTING, PHASE II	2 3 ▲▲	4	0
37		SUBTOTAL MANAGEMENT SYSTEM NO 2 & 3 ▲▲	50	6
38	SYSTEM NO 2 (SUBCONTRACTOR TASKS)			
39	EXEC NO 2 DEVELOPMENT & CHECKOUT		40	34
40	NON EXECUTABLE CODE DEVELOPMENT		12	8
41	REFURBISH PROJECT-ORIENTED ENGRG SOFTWARE		36	15
42	IPAD SUBSYSTEMS & MANAGE/ENGRG SOFTWARE CHECKOUT		90	65
43	IPAD SYSTEM CHECKOUT		75	60
44	IPAD SYSTEM DEMONSTRATION & RELEASE (SYS NO 2)	△	3	12
45	MANAGEMENT		24	3
46	COORDINATION MEETINGS WITH CONTRACTOR			
47	REPORTING		1	0
48	ORAL PRESENTATIONS TO NASA/INDUSTRY		3	0
49	MONTHLY TECHNICAL & MANAGEMENT		2	0
50	FINAL REPORT DRAFT, SYSTEM NO 2		10	2
51		SUBTOTAL SYSTEM NO 2 ▲	296	199
52	SYSTEM NO 3 (SUBCONTRACTOR TASKS)			
53	EXEC NO 3 DEVELOPMENT & CHECKOUT		40	34
54	NON EXECUTABLE CODE DEVELOPMENT		12	8
55	REFURBISH PROJECT ORIENTED ENGRG SOFTWARE		36	15
56	IPAD SUBSYSTEMS & MANAGE/ENGRG SOFTWARE CHECKOUT		90	65
57	IPAD SYSTEM CHECKOUT		75	60
58	IPAD SYSTEM DEMONSTRATION & RELEASE (SYS NO 3)	△	3	12
59	MANAGEMENT		24	3
60	COORDINATION MEETINGS WITH CONTRACTOR			
61	REPORTING		1	0
62	ORAL PRESENTATIONS TO NASA/INDUSTRY		3	0
63	MONTHLY TECHNICAL & MANAGEMENT		2	0
64	FINAL REPORT DRAFT, SYSTEM NO 3		10	2
65		SUBTOTAL SYSTEM NO 3 ▲	296	199
66		TOTAL PROGRAM MANMONTHS AND COMPUTER HOURS	2027	1074

Figure 5-5. Baseline Implementation Plan Schedule and Control Summary

IPAD release capabilities in Systems No. 2 and No. 3 at 51 and 57 months after go-ahead. Estimated development costs include 50 man-months and 6 computer hours for the major IPAD contractor and 296 man-months and 199 computer hours for each of the subcontractors, for a total Phase II cost of 642 man-months and 404 computer hours.

The Baseline Implementation Plan is performed during a period of 60 months at a total cost of 2027 man-months and 1074 computer hours.

5.3.3 <u>Cost distribution curves.</u> – This section presents distribution curves for both man-months and computer hours. Figure 5-6 presents these distributions broken down for each of the major computing systems included in the baseline plan, and paralleling the plan overview shown in Figure 5-5., It can be seen that for development of IPAD in one computing system, the larger expenditure rates occur between 24 and 34 months from go-ahead with peaks of 45 man-months per month and 25 computer hours per month.

The cost distributions for the development of IPAD for system No. 2 are given by the second set of curves, which show the larger rates between 38 and 48 months from go-ahead with peaks of 16.5 man-months and 12.5 computer hours per month. For system No. 3, the curves are almost identical to those for system No. 2 but phased about 6 months behind.

The total distribution curve is shown in the lower set of curves, indicating the larger rates of expenditure between 24 and 34 months from go-ahead, with peak rates of 58.5 man-months and 33.5 computer hours per month.

Table 5-1 gives the breakdown per fiscal year and per computing system for the Baseline Implementation Plan total costs, assuming a go-ahead date at the start of FY 1975.

5.3.4 <u>Variants to reduce peak funding and costs.</u> – This section presents the results of a quantitative evaluation to reduce peak funding and a qualitative assessment of various alternatives to reduce program costs.

A variant to the baseline plan was investigated with the objective of reducing peak expenditure rates. The man-month distribution curves obtained for a 6-month selective stretchout are shown in Figure 5-7 for all three systems. The curve of total cost indicates that the rate of expenditure can be maintained below 40 man-months per month, which is a reduction of 34 percent from the peak expenditure rate of the baseline plan. The breakdown of man-months per fiscal year is given in Table 5-2 for the total costs. A slight increase in cost is due to additional coordination.
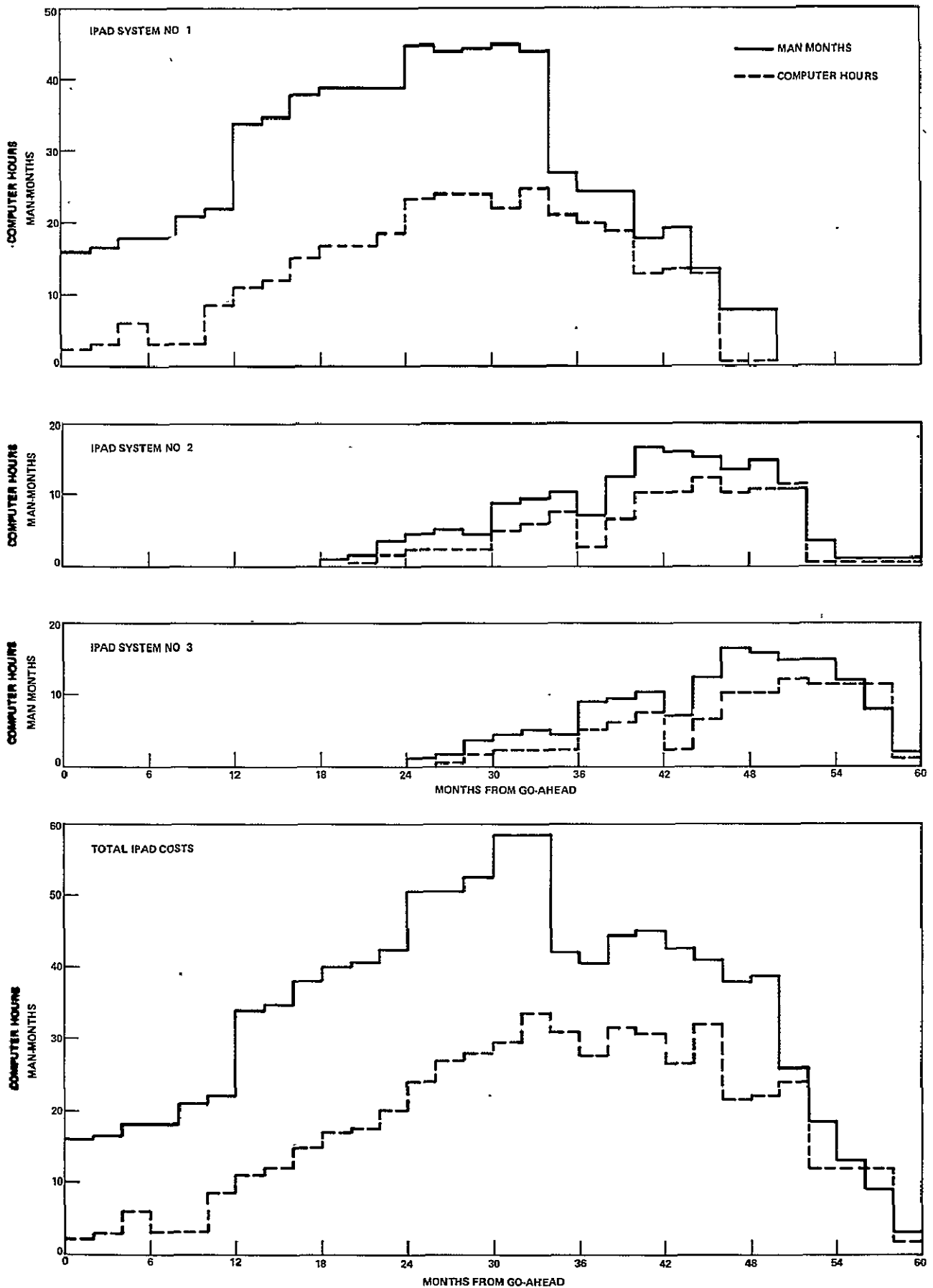
52

Figure 5-6. Cost Distribution Curves for Man-Months and Computer Hours

53

TABLE 5-1. IPAD BASELINE IMPLEMENTATION PLAN, COSTS PER FISCAL YEAR

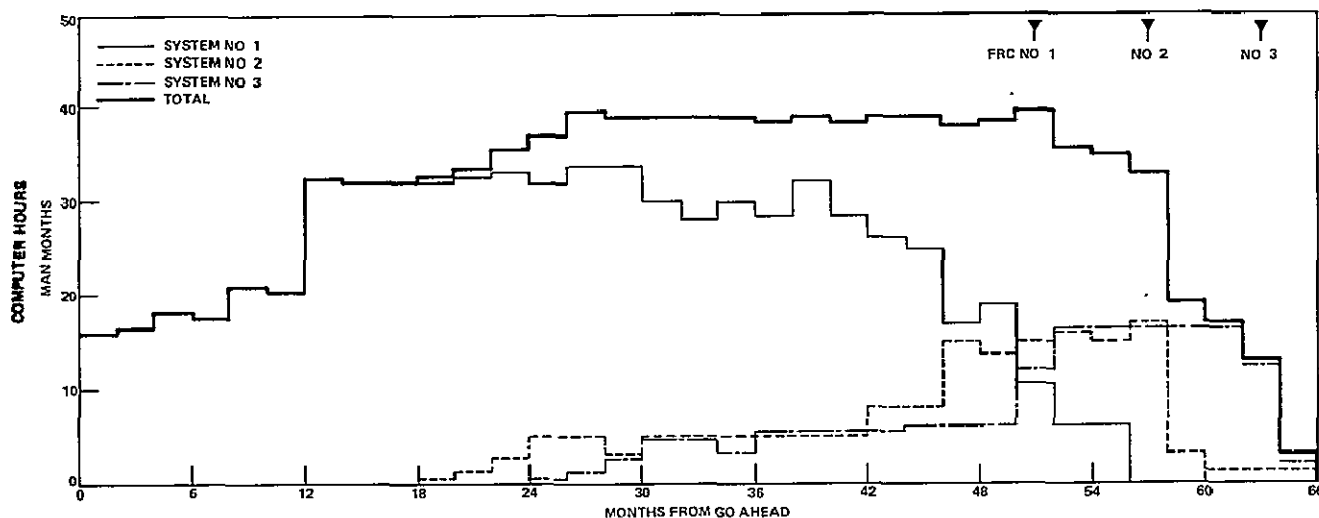| Fiscal Year	System No. 1		System No. 2		System No. 3		Totals	
	Man-Months	Computer Hours	Man-Months	Computer Hours	Man-Months	Computer Hours	Man-Months	Computer Hours
1975	220	51	–	–	–	–	220	51
1976	444	180	12	4	–	–	456	184
1977	495	279	84	50	40	16	619	345
1978	210	159	160	103	129	76	499	338
1979	16	1	65	45	152	110	233	156
Totals	1385	670	321	202	321	202	2027	1074

Figure 5-7. Six-Month Stretchout Variant to IPAD Implementation Plan

Various alternatives were qualitatively assessed to explore means of reducing the peak funding and/or costs of the overall plan. Table 5-3 presents the more realistic alternatives.

It must be recognized that the baseline plan was a minimum-risk, minimum-cost plan; none of the alternatives can be recommended.

TABLE 5-2. SIX-MONTH STRETCHOUT IPAD
IMPLEMENTATION PLAN BREAK-
DOWN PER FISCAL YEAR

Fiscal Year	Man-months
1975	220
1976	398
1977	470
1978	470
1979	410
1980	80
	2038

TABLE 5-3. IPAD DEVELOPMENT ALTERNATIVES TO REDUCE COSTS

	Advantages	Disadvantages
Delay support from manufacturers #2 and #3	a. Reduces peak funding.	a. Delays IPAD on other computers. b. GPU RFPs restricted to one computing system's users. c. Reduction in "competitive incentive" to manufacturers and GPU bidders. d. All eggs in one basket.
Circumvent GGL	a. Reduces cost slightly (no GGL specs required). b. Reduces peak funding.	a. GPUs not transferable, must be re-programmed for computers #2, #3. b. Subsequently developed graphics OMs and GPUs not transferable. c. Much needed national standard delayed substantially.
Delay STATUM	a. Reduces peak funding slightly.	a. Insignificant peak-funding reduction. b. Useful utility not available at first release.
Delay GDM	a. Reduces peak funding sub-stantially. b. Significant schedule relaxation. c. Increases competition. d. Probably reduces cost.	a. Principal GPU used by designers not available. b. Longest learning cycle code comes last. c. Designers cannot support IPAD-assisted project schedules. d. Higher risk to IPAD success.
Do not provide training and demonstration	a. Less cost. b. Earlier contract termination.	a Delay acceptance of IPAD. b. Delay benefits provided by IPAD. c. Higher risk to IPAD success

5.4 IPAD System Operational Costs

A more detailed discussion of these costs can be found in Volume VI, Section 3.

Operational costs as required to support an IPAD environment are concerned with computing-facility hardware, computer support and maintenance, software maintenance, and the use of time and human resources.

The computing-facility hardware, support, and maintenance costs include main computers, minicomputers, communications interface, various types of terminals, computer operations, system software maintenance, and accounting support. These costs are typically combined into a computer allocation charge that is passed on to the user in the form of a rate per usage unit. This is usually a direct charge; however, the cost distribution algorithm and whether any of the costs are allocated to overhead can have a significant effect on the operational costs to a project.

The cost distribution algorithm strives for two things: (1) ensure that the charges against the projected computer work load will pay the computer hardware and support costs, and (2) try to distribute the user charge equitably across the hardware used. For an IPAD environment, it appears that the best way to handle interactive terminal charges is to have an easily visible "residency" charge that is separate from the actual computer computation cost. This approach lends itself to more accurate comparison of costs in doing jobs interactively. Due to personnel time conflicts, the inevitable computer hardware/operating system problems, etc., only 60 to 80 percent of the interactive terminal scheduled time can be realistically planned to produce revenue. That is why 100 hours per terminal per month (one shift) has been selected as a target utilization to determine rates. Production drafting, numerical control parts programming, circuit board layout, and packaging can be scheduled for two shifts.

There are many possible computer and terminal configurations. "Typical" computer computation cost varies between $250 and $1200 per "computational hour." This wide spread results from differences in cost distribution algorithm, computer support personnel in the computer allocation, people or hardware on overhead, and even project accounting or fund distribution methods. The same hardware may cost users different amounts depending on whether it is purchased or leased and whether the lease is long-term, second-party, with or without maintenance, etc. When variations in charges for priority handling (two-hour turnaround, overnight, etc.) are added to this, it becomes apparent that operational cost evaluations must be made on specific circumstances and data.

Although software development costs are not part of the operational cost, the interactive character of an IPAD environment will imply an increased use of interactive programs and will indirectly have an impact on operational costs through increased equipment requirements and software maintenance. Interactive environment programming requires more consideration of the user and his personal involvement during the program design and development than for batch programming.

The impact of time and human resource considerations on operational costs within an interactive environment are mainly associated with the time saved in the design process due to shorter problem-solving cycles and reduced turnaround times. The benefits to the user are varied and depend on which of the possible advantages he wishes to exploit. The reduction in time to do a given task may be regarded as an opportunity to exercise some management decision options not available before. Each option has its own payoff and can be selected in light of the long or short term benefits to the project and the company. As a consequence of these options and the present state of development and implementation, a quantifiable impact of the use of interactive terminals on the total design process has so far eluded a firm, empirical definition. Convair's experience has shown that engineering manhours are reduced with the use of interactive equipment. Tasks have ranged from one half to one twentieth of the original time. Figure 5-8 summarizes some of the options available to take advantage of the time saved. The assumption made of an average of 5:1 time reduction in production development cycles stems from the Department of Defense Conference on CAD/CAM in Davenport, Iowa; current results confirm this prediction.

REDUCE PRODUCT
DEVELOPMENT TIME BY 5:1

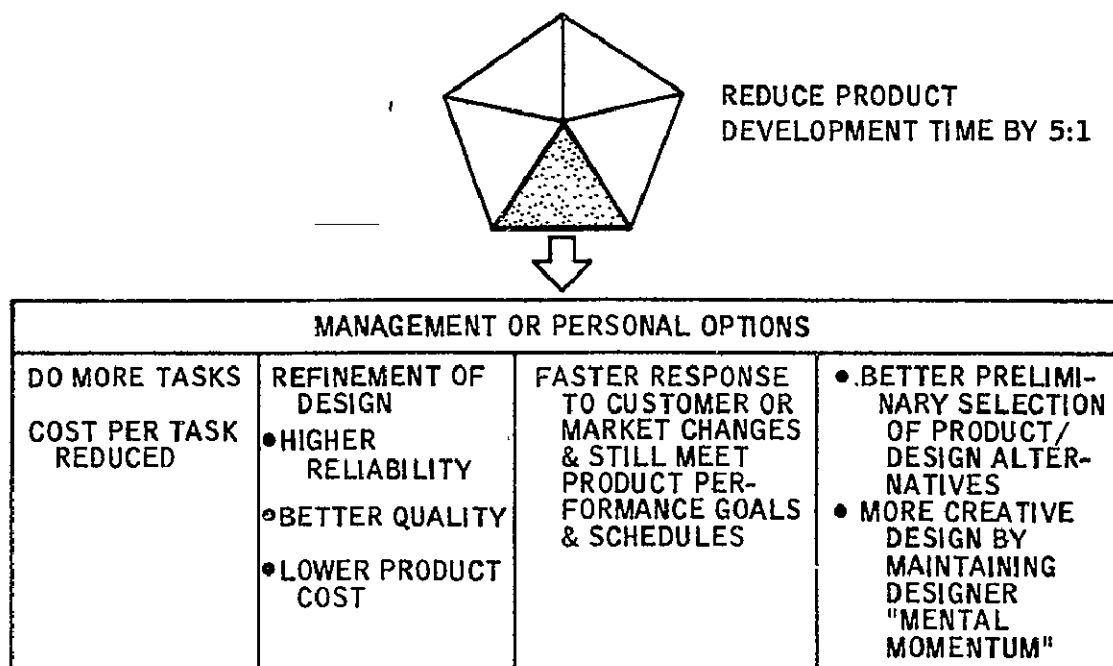| MANAGEMENT OR PERSONAL OPTIONS			
DO MORE TASKS COST PER TASK REDUCED	REFINEMENT OF DESIGN ●HIGHER RELIABILITY ●BETTER QUALITY ●LOWER PRODUCT COST	FASTER RESPONSE TO CUSTOMER OR MARKET CHANGES & STILL MEET PRODUCT PERFORMANCE GOALS & SCHEDULES	●.BETTER PRELIMINARY SELECTION OF PRODUCT/ DESIGN ALTERNATIVES ● MORE CREATIVE DESIGN BY MAINTAINING DESIGNER "MENTAL MOMENTUM"

Figure 5-8. Options Available to Use Saved Time

In light of the preceding discussions, it becomes apparent that it is difficult to quantify and estimate projected operational costs within an interactive system such as IPAD. Further, it is difficult to quantify cost improvements associated with operation within an IPAD environment, since available benchmarks are inadequate. Assessment of operating costs was undertaken with this realization, and the identified sources of increases and decreases of these costs are summarized in subsections below.

5.4.1 Identifiable cost increases. - There are three areas of cost increase identified to IPAD operations:

1. Computer costs of each Operational Module execution will increase due to the overhead associated with:

   a. IPAD's EXECutive.

   b. Data Base Management System.

2. Computer costs of each Operational Module execution will increase due to the additional hardware required to support IPAD and to the corresponding operating system maintenance costs.

3. Interactive terminal costs will add to manhour costs whenever the user is at a terminal.

Each of these factors is discussed in more detail in Volume VI, Section 3.1.

Estimates of cost increases have identified the required expansion of the host computer hardware with a 13-percent overhead and the Data Base Management System with an overhead that averages between 4 and 12 percent, but could climb as high as 20 to 60 percent at an extreme. However, it is unlikely that the 60-percent figure could ever be reached. IPAD operation could average a 25 percent increase (13 percent + 12 percent) per Operational Module execution.

5.4.2 Identifiable cost decreases. - Most costs associated with human resources are expected to decrease in an IPAD environment:

1. The manhour costs associated with each OM execution will decrease due to:

   a. Use of EXECutive and Task Control Sequences for tasking.

   b. Use of the General Purpose Utilities for:

- Configuring the User File data sub-base (Query Processor)

- Collecting and storing the task initiation data (Query Processor)

- Examining Operational Module results (Query Processor and General Graphics Plotter)

- Optimizing or parameterizing (OPTUM)

- Graphing (General Graphics Plotter)

These costs are partially offset by the computer costs associated with executing the General Purpose Utilities.

2. The manhour costs associated with each design task will decrease due to:

a. Use of the SCHEMA assembler for task integration.

b. Use of the Executive's RECORDER for saving Task Control Sequences for later re-execution.

c. Use of the Executive's WRITER for constructing general purpose Task Control Sequences.

d. Use of the Executive's EXPANDER to construct Task-specific Control Sequences.

e. Use of Task Control Sequences to construct and review presentations of design data.

f. Use of project review files to communicate analysis results in a simple yet highly effective manner (similar to a viewgraph presentation and/or a movie).

3. Manhour costs associated with project management will decrease due to:

a. Close management control of all official project data.

b. Increased visibility afforded by:

- Instant availability of all current design data contained in the project data bank.

- Timely communication to all levels of the project structure via tutorial-aid support.

- Effective communication on current evaluation of the design through the project review files.

- Availability of an in depth track of any user task via its User Task Trajectory.

c. Decreased vulnerability afforded by:

- Effective control of data access (privacy)

- Roll-back of the data base (recovery)

Substantial cost savings can result for the operation of an IPAD System if:

1. The engineering user is adequately assigned parallel or quick-reaction tasks to offset his propensity to over-engineer.

2. Rising computer costs do not negate the expected manhour savings.

The first statement outlines a problem that only the project management can solve. The second problem can be mitigated by the creation of efficient - in both time and core requirements - code associated with Data Base Management Systems. This responsibility rests with the host computer manufacturers.

5.5 IPAD System Benefit Assessment

A more detailed write up on this task can be found in Volume VI, Section 4.

A typical aerospace vehicle design process was examined in Task 1 "Characterization of IPAD System" by having a competent engineer from each of the selected technical disciplines explain how he performed his task and the tools he used to do it. The design process was seen to consist of two basic tasks, namely.

1. Creative tasks (e.g., management planning, vehicle configuration design, subsystem design).

2. Data generation and manipulation tasks (e.g., routine analyses, trade off and sensitivity studies).

The major deficiencies in the present design process (typically common to all aerospace companies) are as follows:

1. It is becoming increasingly difficult to meet Customer requirements for designing higher performance vehicles in a shorter period of time and at a lower cost.

2. There is lack of timely visibility and data communication in some of the evaluation processes because man is not interactively in the loop during key portions of the problem-solving procedures.

3. Some tasks are still discussed and treated as if no "common thread" existed between the various disciplines.

4. Quite frequently some significant disciplines do not get their inputs into the design process with the required emphasis in a timely manner.

5. Inconsistencies exist in different disciplines both in outputs and inputs to computer programs using the same type of data, and also there is some duplication of subfunctions among computer programs.

The impact of these difficiencies on the aerospace vehicle itself is a combination of one or more of the following effects:

1. Degraded performance.

2. Increased costs.

3. Inability to meet some of the short time schedules imposed by the Customer.

An IPAD-type system would correct or mitigate the present design process deficiencies and would result in tangible and intangible benefits as summarized in the following paragraphs:

5.5.1 Impact on aerospace-vehicle performance. - An IPAD system is expected to have the following impact on aerospace vehicle studies, which in turn will result in improved vehicle performance:

1. IPAD with man in the loop will allow faster analysis, will permit more comprehensive vehicle and subsystems sizing and optimization, and will permit more complete tradeoff studies with an integrated participation of various disciplines.

2. Higher management confidence that the resulting design will be better because all groups will work from a common data base, because IPAD's faster capability makes it easier and faster to evaluate alternate design solutions, and because the selected design will have better reasoning and backup behind it.

3. The effects of design changes on configuration, performance, and costs will be easier to predict.

4. Although opinions vary on how much design calendar-time can be saved and how much design costs can be reduced by using IPAD, the calendar time for design freeze has to be reduced and the costs decreased because of the quicker iteration loops possible with IPAD.

5. Should enable zeroing in on the best design more quickly allowing more detailed study of the selected design.

5.5.2 Impact on engineering work. - IPAD is ideal for tasks requiring the generation, storage, and manipulation of large volumes of data. Typical examples are engineering team evaluation and design tasks associated with an aircraft project, such as vehicle configuration and subsystems design, repetitive routine analysis, and tradeoff and sensitivity studies. The need to access large data bases and operate with a multitude of data subsets is typical of project tasks in all disciplines. This requires streamlined data accessibility and communication capability such as provided by an IPAD system. Furthermore, an improved problem-solving engineering capability will be fostered by IPAD, resulting in shorter evaluation schedules and reduced engineering costs. Thus, IPAD is seen as having the following near-term and far-term impact on engineering work:

1. Designers and engineers will have a more prominent participation in the design process by efficiently operating and controlling the IPAD system. Creative and evaluation functions will be performed much more economically with IPAD than with a batch-mode operation.

2. The quality of design tradeoff, and optimization studies will improve because the analyses will be integrated and cover more significant interdisciplinary variables.

3. A "Data Bank Administrator" will be required within a project operating with an IPAD system to force consistency of the data base and to ensure proper identification and storage of project data.

4. It will cause the routine drafting tasks to become more automated while maintaining the creative design tasks under the control and proficiency of the user.

5. For the test groups the traditional formats of data reduction and presentation could be automated so that the data output can be readily entered and evaluated within an IPAD system.

6. Estimating tasks will tend to use grass-root approaches and will become more automated.

7. Special management operating modules and automated status reports will give management greater visibility, and will enable management to make decisions in a timely manner, consistent with shorter design schedules envisioned for IPAD.

8. The skill mixture in the engineering department will change (e.g., the number of engineering aides should de crease, but the number of engineers who can perform their job within IPAD environment would increase; the net effect would be a reduction in total manpower).

9. Report preparation can be simplified by the hard-copying feature of interactive graphics and the need for reports can be reduced by storing the data in the project data banks, available to all users.

10. Since IPAD will effectively cope with the data generation and manipulation tasks, implementation of IPAD will give the engineer more time to devote to creative tasks.

5.5.3 Impact on disciplinary interfaces. - Several of the present design process deficiencies are strongly due to inadequate consideration or lack of timely data communication among interfacing disciplines. An IPAD system will substantially mitigate these problems because it will:

1. Require consistency of the data base in all disciplines through the "Data Base Administrator".

2. Require the clear definition of all interfaces because IPAD operates as an integrated system.

3. Require sizing and optimization studies to be considered from a wider interdisciplinary point of view rather than from each single discipline viewpoint.

4. Require analytical, design, test, and management personnel to work in a timely manner as an integrated team.

Solution of interface problems in IPAD will also result in an upgrading of personnel by increasing their interdisciplinary capability. This greatly benefits manpower planning and assignments in companies or organizations that execute multiple programs simultaneously.

5.6 IPAD System Impact on Company Organization

A more detailed discussion of this area can be found in Volume VI, Section 5.

Although no two aerospace companies have the same organizations, they all fall within one of two basic types, namely a functional organization or a project organization. In line with its flexibility, the intention is to implement IPAD within the existing functional or project organizations in any company, with the proviso, however, that such existing functional or project organizations "bend a little" in order to exploit IPAD features. What is involved in this "bending" is described in the following sections.

IPAD's implementation calls for an IPAD manual and a top level management policy that specifies the circumstances and conditions under which IPAD shall be implemented on its programs. Each company would have flexibility in preparing its IPAD manual in the same manner that it now has in preparing any of its manuals.

Sanction of IPAD by top level management has the following significant implications:

1. It requires that the responsibility of each group in IPAD be defined in the company "Standard Management Practices" manuals and that this responsibility be executed.

2. It requires that management/engineering members of a project team have access to "balanced" capabilities mounted on the IPAD system.

3. It requires that management and users of IPAD contribute to company plans for "Capital Facilities" requirements for IPAD.

4. It requires implementation of training programs to instruct people on the IPAD system features and to train people to use IPAD effectively.

5. It allows IPAD to compete for company Independent Research and Development (IRAD) funds to improve it.

If IPAD is operational in a company's computer installation, its features and capabilities will be available irrespective of the user being a single individual under a functional organization or a project team. In the early stages of evaluating a new idea and before it evolves into a "project", there may not be a need to mount a team capability on IPAD since the "team" has not yet been formed; individual users, though, can nevertheless operate under the IPAD system with whatever capability they install on it to evaluate the new ideas. The aforesaid remarks imply that implementation of IPAD could be easily accomplished by both existing company functional and project organizations.

To assist in executing a given project, current functional organizations furnish the required technical and business manpower, facilities, and test equipment. In an IPAD environment they will additionally accomplish the following tasks:

- Develop, adapt, maintain, and improve the IPAD system and its components.

2. Train and/or assist in training personnel in the coordinated use of IPAD as a working tool. The training must also teach "when to use IPAD on what projects" and "when not to use IPAD and on what projects" such that man will control IPAD and not vice versa.

3. Supply a Data Base Administrator and other technical and business personnel to a project office to assist in the implementation of IPAD for the project.

Actual execution of projects in most companies is usually accomplished by a project organization. The use of IPAD is best suited to a project organization where it is required to respond quickly in an integrated manner. Changes to project organization will include the following:

1. The assignment to the project of personnel from functional groups who understand IPAD and are dedicated to making it work efficiently for them.

2. The addition of a "Data Base Administrator" who reports directly to the Project Director.

3. The use of automated management techniques to permit timely interfaces with quicker engineering evaluation cycles and shorter response times made possible with IPAD.

It is seen that the near-future change to existing organizations, procedures, and practices is extremely modest. Thus, an initial IPAD "makes full use of existing organizations and design processes that work" and superimposes on them relatively modest changes in order to remove some of the deficiencies in these design processes and result in improved performance, decreased costs, and shorter schedules to complete the tasks.

Changes in design organizations to further exploit IPAD in the distant future cannot be precisely forseen and defined at this time. However, conjectures on what some of these future changes might be are:

1. Discipline groups in both functional and project groups may disappear in some companies and be replaced with "system groups." For example, the current discipline groups called "Materials, Structural Dynamics, Stress, Mass Properties, and Structural Design" may be replaced by a single "Structural System Group".

2. Certain operations, with corresponding change in organizational structure, may be eliminated. For example, some detail drawings and loft

boards may be eliminated by having the designer through IPAD generate, store, check, and transmit design data directly to a numerically controlled machine.

3. Because of the integrated team effort required by IPAD, some levels of supervision may be completely eliminated.

4. With expanded use of IPAD, economic considerations will have a hand in shaping the organization. For example, the administrative function called "Planning and Control" may be implemented in the group where the work is actually done.

5. A given discipline group or a given system group may be asked to perform a new task that it had not done before and/or relinquish others that it had done heretofore.

6. Each company using IPAD will try to learn from its competitors and implement profitable changes in organization.

7. As IPAD expands there may be a need for an individual in the project organization to ensure that IPAD is used properly and with common sense.

5.7   IPAD Spin-Off Assessment

More details on this assessment can be found in Volume VI, Section 6.

IPAD spin-off in all non-aerospace fields, either as conceived for aerospace vehicles in this study or suitable variations thereof, will correct or mitigate deficiencies in the solution of technical and business problems where voluminous data is generated and manipulated. In these other fields, just as in the aerospace field, IPAD will provide a fast response interactive environment to enhance the creative thinking done by a team of people having the responsibility for planning, problem solving, controlling, and managing a specific project or investigation. Since the Hardware/Software complex required for IPAD can be used in all fields of sciences and engineering, it has to be developed only once, and non-aerospace field teams must only provide their own automated capability to solve the problems peculiar to their disciplines and field.

The following sections identify potential spin-offs in greater depth. These spin-offs are seen to take place in both near-term and far-term time frames.

5.7.1 <u>Spin-off in technical non-aerospace fields.</u> - These fields include:

1. Transportation. Since aerospace vehicles are essentially a mode of transportation it is expected that the first near-term spin-offs in the use of IPAD will be in other modes of transportation, such as:

   a. Marine transportation (e.g., water surface vehicles and underwater vehicles including underwater weapons like torpedoes and missiles).

   b. Ground transportation (e.g., automotive and mass transportation engineering, ground and underground).

2. Communication (e.g., design and manufacture of hardware, traffic control, and message control).

3. Electronics (e.g., design and manufacture of hardware). Some segments of the electronic manufacturing industry already employ IPAD-type systems where the electronic design engineer does his total job at interactive terminals.

4. Civil Engineering

   a. Design and analysis of large structures (e.g., buildings, bridges, towers, and dams).

   b. Surveying (e.g., contour mapping).

   c. Highway and freeway layouts.

   d. Pollution containment and control.

   e. Hydrology.

   f. Airport design.

5. Nuclear Engineering (e.g., design of reactors).

6. Mining Engineering (e.g., oil and mineral exploration).

7. Chemistry (e.g., automatic chemical analysis and identification).

8. Meteorology (e.g., real time global weather monitoring and prediction).

9. Mechanical Engineering.

   a. Design and manufacture of machined-part hardware (e.g., go from an interactive terminal to a machine shop, by-passing the drawing cycle).

   b. Minimize rework and scrap through Computer Aided Manufacturing (CAM).

10. Radio Astronomy.

11. Architecture (e.g., rapid pictorial and configuration displays).

12. Seismology.

13. Literature Retrieving (e.g., use IPAD-type techniques to help technical personnel keep abreast of the "literature explosion").

14. Computer Hardware and Software. Design, development, and manufacturing of improved IPAD-type systems and computer hardware and software.

It is noted that IPAD is ideally suited to solve interdisciplinary problems that have heretofore been looked at only in a fragmented manner. For example, the pollution problem has many facets and, in addition to the pollution sensing and mitigating devices, it involves and must consider sociological, transportation, manufacturing, communication, legal, and policing problems in order to obtain an acceptable integrated solution. Similarly, the energy problem must consider existing forms of energy, available supply and location, consumption locations and rates, rationing, and development of new forms of energy to obtain a satisfactory integrated solution.

5.7.2 <u>Spin-off in business non-aerospace fields.</u> - Just as in the case of the technical fields, IPAD-type systems will be beneficial to handle business problems in non-aerospace fields where voluminous data is generated and manipulated. The end result of application of IPAD-type systems to business problems will be a combination of improved performance, decreased costs, and meeting short time schedules imposed by the Customer.

Illustrative examples of both near term and far term spin-offs in the use of IPAD-type system in business non-aerospace fields and areas are:

1. Maintenance Management. Both industry and government have been faced with the problem of maintenance costs that over the life time of some expensive products have been higher than the original cost of the product. Systematic integrated analyses of these products should result in a marked reduction of maintenance costs to a small percentage of the original cost.

2. Inventory Control. In cases where an organization has many products sold or used in many stores or departments and in many locations.

3. Conservation of Energy. To make systematic and integrated analyses of the way energy is used with the view of conserving energy and saving costs without reducing efficiency.

4. Legal Field. Use an IPAD-type system to quickly retrieve legal literature, particularly pertinent court rulings and decisions on cases.

5. Econometrics. Presently there are modeling techniques being used, such as the Wharton School national economic model, for getting an insight into the future effect of today's economic policies. Significant benefits would accrue through integration of models created by various agencies, such as the Environment Protection Agency, the Department of Agriculture, and the State Department. The use of natural resources and remaining reserves in this country and abroad, need to be modeled for their effect on resource prices and the balance of payments. The potential of developing integrated models with multidisciplinary interfaces is obvious. Each agency and specialty will be charged with continually updating its own modeling and evaluation capabilities so that the total model represents the best planning tool for everybody.

6. Marketing Prediction. To develop models and display results of marketing studies pertaining to goods, services, and entertainment.

7. Hospital Administration. Economy in the delivery of health services will foster more integrated application of computer technology than is presently achieved. IPAD-type systems can improve the use of medical data banks and statistics to help in providing more cost-effective health services and lower administrative costs.

8. Education. From the point of view of transmitting knowledge, the teaching function is one of communications and systematic exposure of the students to "theory, examples, practice, historical cases, etc." associated with the subject at hand. Imbedded in this process is a continuous need to "visualize" examples, cause-effect relationships, end results, etc., which typically consumes a large percentage of the year or semester hours. The assembling of large multi-subject banks of interactive programs with pertinent examples, historical cases, etc. and organized on a subject basis, could provide a teacher-directed interactive system with the following features:

    a. The teaching process would be accelerated, mainly by removing most of the time-consuming drudgery for both teachers and students.

    b. The cost of higher education per professional would be reduced because of shorter educational cycles.

    c. The capital investments per educational facility may go up to account for computer and special interactive equipment.

    d. Graduating students could be exposed to many real life problems and will have a more comprehensive preparation for professional life.

9. Streamlining Procedures and Reducing Paperwork. IPAD-type thinking will require people in business areas to streamline procedures and reduce paperwork (e.g, banks, post office, hospitals, real estate, brokerage houses, welfare and tax agencies).

Since IPAD is a new tool, the extent of its full broad utilization will become evident in an evolutionary manner.

6 CONCLUSIONS

The major conclusions derived from this IPAD feasibility study are:

1. The implementation of an IPAD system in one major computing system is feasible within four years from go-ahead. With sufficient planning and effort the deployment of IPAD to two other computing systems can be effected at subsequent 6 month intervals. The implementation of IPAD in one computing system requires 68 percent of the funding for three systems.

2. The conceived IPAD design is an interactive system having unlimited flexibility to accommodate small or large project teams.

3. IPAD is a user-oriented, modular system using advanced data base management concepts that cater to the total design process.

4. The IPAD system provides a computing environment usable in many other non-aerospace fields.

5. IPAD use can be easily absorbed within a company, but upper management commitment is required for its utilization.

6. In order to implement a viable IPAD, languages must be developed and implemented to provide IPAD interface with a Data Base Management System and interactive graphics support software. Transferability considerations require that the same languages be implemented by all pertinent manufacturers.

7. As a practical approach, it is envisioned that NASA will sponsor the required language development to ensure meeting IPAD schedules. Aside from the influence of the schedule, the languages should evolve from a CODASYL-like committee under the cognizance of both CODASYL and ANSI to ensure acceptance as a standard. Implementation is to be ensured by the potential IPAD-user market and through representation of the vendors on the committee.

8. Participation in the development of IPAD should be given to various aerospace companies, government agencies, and universities to ensure that the best know-how will bear on its design and implementation.

9. Priority should be given to the development of critical IPAD framework software, while refurbishing existing engineering operational modules as required for checkout and demonstration of IPAD.